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NERVOUS CONTROL OF RESPIRATION

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THE complexity of the respiratory activity denotes a complex nervous center, subject to chemical and to nervous influences, and expressing its activity by means of several motor mechanisms. There are three anatomically separable muscle groups involved: the nasopharyngeal, only used in forced respiration and under control of the facial nucleus; the laryngeal under control of the vago accessory; and the thoracic with its rib part under control of the anterior horn cells of the intercostal nerves, its diaphragmatic part under control of the phrenic. I propose to present an interpretation of experimental evidence dealing with the nervous control of respiration accumulated through the efforts of various investigators. In many instances there will be no specific recognition of their contributions. My reason is that time permits only an exposition of certain of those more recent investigations of the subject in which the recording of nervous impulses by the combined use of vacuum tube amplification and inertialess oscillographs has made further progress possible.

It seems definitely established that a bilateral group of cells in the substantia reticularis, extending from the level of the calamus scriptorius to the level of the atlas (Flourens, 1842), (Gad, 1893), constitute a pacemaker mechanism for the total respiratory reflex apparatus. This group of cells initiates activity in a chain of motor nuclei which innervate the muscles concerned in the respiratory act. Impulses from the midbrain influence both groups of neurons in a manner altering the rate and the

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depth of respiration. Impulses from centers above this level exert relatively little tonic influence, but psychic influences arising therein can modify respiration to a marked degree.

The pacemaker mechanism is itself functionally separable into two divisions, one group of cells initiating inspiration, another group expiration. There has been and still is a divergence of opinion as to the nature of the pacemaker cells. Some attribute to them an intrinsic rhythm which is not initiated by afferent impulses from the periphery; others consider their activity as always consequent upon such. To us the demonstration that a periodic discharge of action potentials may be recorded from the phrenic nerve after section of the vagi and complete cessation of bodily movements by curare (Winterstein, 1911) is considered proof of their power of intrinsic rhythmic activity. While proprioceptive impulses are not eliminated in this experiment, they would presumably be continuous and could not, therefore, readily be conceived to account for a periodic discharge. The discharge from the centers after section of the vagi and curarization is slower than before. This observation has been confirmed by Adrian, Bronk, and Phillips (1932), and by Adrian (1933). Recently the recording of periodic impulses from the intercostal muscles corresponding with both inspiration and expiration is considered further definite evidence in support of the assumption that there is an inspiratory and an expiratory division to the respiratory center. Expiration always preserves its phase relationship to inspiration. The activity of the expiratory center may be initiated independently by an afferent discharge from the stretch receptors of the lung. Its activity may be modified by proprioceptive impulses from the structures determining the air resistance in the larynx, the nasopharynx and the body generally. In normal respiration activity in the expiratory center is relatively slight, in forced respiration it becomes definite.

If the evidence for an inspiratory and an expiratory center possessing an intrinsic rhythm not initiated by periodic afferent impulses is valid, a fundamental physiologic principle is thereby established. According to older concepts, as expressed in the Hering-Breuer theory of the autonomic control of respiration, afferent impulses were required to initiate activity in the ganglion cells controlling both inspiration and expiration. According to our present interpretation the activity of these cells is autochthonous and is simply modified by afferent impulses. It is granted that the evidence presented is not a demonstration of the autochthonous rhythm of *single* ganglion cells, inasmuch as the impulses led from the phrenic and the intercostal nerves in the experiments cited arise from groups of ganglion cells in synaptic connection one with the other. Evidence secured by us in a study of the activity of the ganglion cells of the excised median cardiac nerve of Limulus polyphemus does, however, indicate that such a single ganglion cell rhythmicity is probable

(Heinbecker, unpublished). It has been possible to record slow, smooth potentials apparently from single ganglion cells in portions of the nerve cord less than 3 mm. in length completely severed from all connections with the heart.

One may here refer to the investigation of Lumsden (1923) in which sections were made through the brain stem of cats and rabbits at various levels to isolate the divisions of the respiratory center. On the basis of the experimental findings four divisions were located: a primitive gasping center in the medulla, an expiratory center just above this, an apneustic center at the level of the acoustic striae and a pneumotoxic

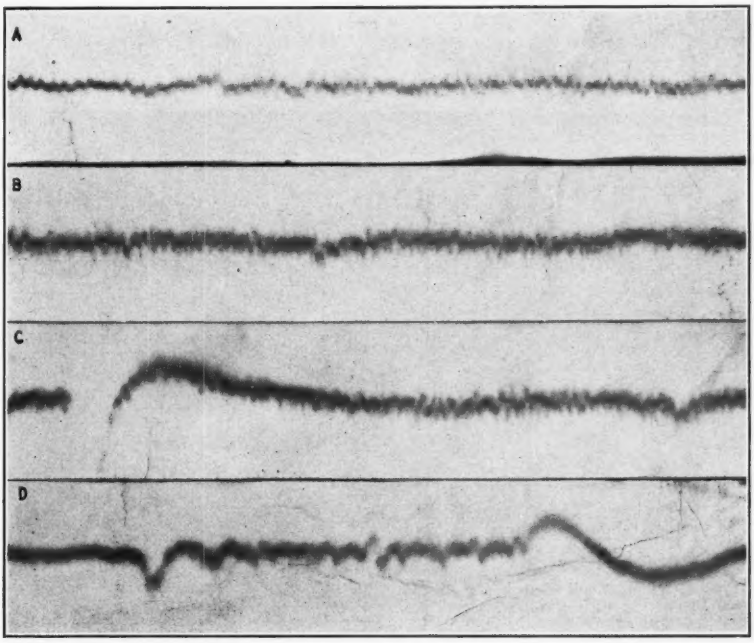

Fig. 1.—*A*, Record of potential changes in the cat vagus nerve resulting from stimulation of peripheral sensory endings on inflation of the lungs. Cathode ray oscillograph amplifier combination.

B and *C*, Record of long continued activity in the cat phrenic nerve after decerebration but with the vagi intact. Only a portion of the activity period is recorded, as it lasted for several minutes. The large deflection of the base line at the end of record *B* and near the start of *C* is the result of mechanical movements of the nerve on the electrodes.

D, Record from the same phrenic nerve five minutes later when the discharges became periodic as in normal respiration.

center in the upper half of the pons. The latter center is pictured as periodically inhibiting the apneustic center whose function is to hold the inspiratory tone high until it is itself depressed by anoxemia to a point where expiration can occur. Anoxemia stimulates the gasping center which is active until reoxygenation is adequate to restore the irritability of the apneustic center which then inhibits gasping. The vagus afferents

check the activity of the respiratory centers. Carbon dioxide stimulates them if the supply of oxygen is adequate to preserve their vitality; anoxemia depresses the centers, especially the apneustic. The known facts of respiration can be harmonized fairly well with such a theory, but it is to be remembered that the experiments employed were acute with the factor of trauma always present and other investigators (Henderson and Sweet, 1929) have presented evidence contrary to that of Lumsden. Repetitive responses can be aroused in certain basal ganglia of the brain by trauma (Bishop, unpublished data). It is therefore possible that the continuous activity of the apneustic center in the animals studied is not a normal phenomenon. Evidence of such continuous activity in the respiratory center under certain conditions is readily obtained (Fig. 1).

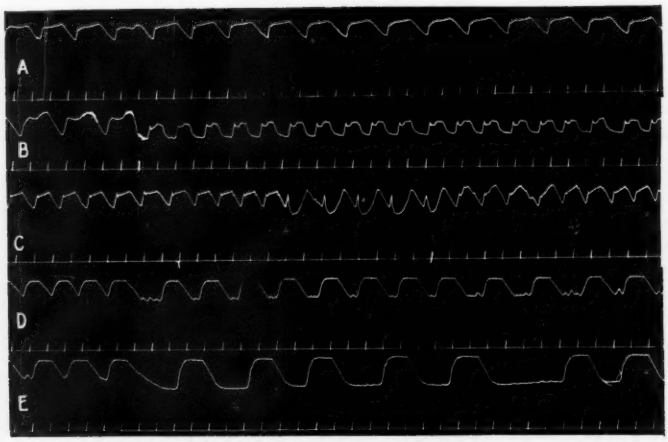

Fig. 2.—*A*, Pneumogram showing normal respiration of decerebrate cat.
B, Effect of weak stimulation of saphenous nerve.
C, Effect of strong stimulation of saphenous nerve. Activity in the largest afferent fibers of the nerve (weak stimulation) results in a depression of inspiration and of expiration. Stimulation of all the afferent fibers including pain fibers (strong stimulation) results in jerky respiration but with an augmentation of both inspiration and expiration.
D, Slowing of respiration effected by cutting one vagus nerve.
E, Slowing effected by cutting both vagus nerves.

The afferent impulses which modify the activity of the respiratory center are derived from several sources. There are those which arise from end-organs in the nasopharynx and the larynx, in the lungs, and in the respiratory muscles of the thorax. Pain impulses, arising anywhere in the body, and psychic influences modify respiration, but the most important regulatory impulses are those coming via the vagus nerves from the stretch receptors in the lung.

When the vagus nerves are divided in the neck, respiration is slowed. Inspiration is prolonged and the expiratory pause is much lengthened

(Fig. 2). Impulses recorded by means of the cathode ray oscillograph from peripheral ends of the divided vagus nerves show that there is a rapid discharge of impulses throughout the period of expansion and early contraction of the lungs (Fig. 3). No demonstrable impulses arise during the expiratory pause. The function of these impulses is apparently to shorten or cut off the inspiratory act and to initiate expiration. In this manner the phase relationship of inspiration to expiration may be maintained.

The frequency and the amplitude of the impulses vary with the rate and degree of expansion and collapse of the lungs. Adrian (1933, loc. cit.) has studied the action of the vagus in the cat during respiration by recording impulses in single afferent fibers. His findings indicate that stimulation of a lung stretch receptor results in a succession of impulses. In normal breathing the frequency of the discharge along single fibers varies from 50 to 100 per second and probably never goes

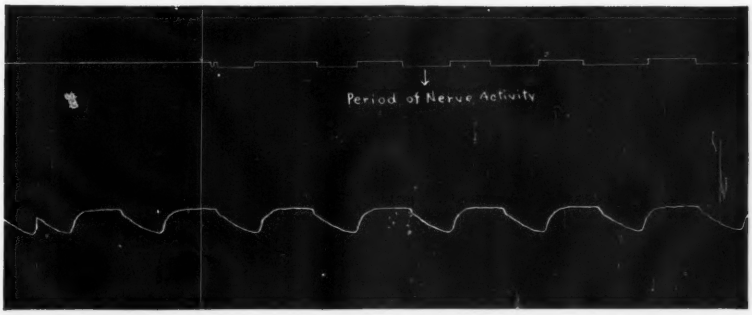

Fig. 3.—Pneumogram of cat, downstroke inspiration, shows the relationship of the period of afferent vagus nerve activity during normal respiration, as visualized on the face of the cathode ray oscillograph, to the respiratory phases.

above 300 per second. The end-organs in the lung behave like muscle spindles in that they become slowly adapted to the stimulus.

In experimental conditions in which a negative pressure is applied within the lungs or strong positive compressing pressure on the thorax in the rabbit, afferent impulses are initiated in the lungs and tissues about the root of the lung which ascend the vagi to result in an inspiratory movement. Such impulses do not develop in normal respiration. The stretch receptors are little affected by concentrations of carbon dioxide up to 10 per cent, by chloroform vapor up to 2.5 per cent, though higher concentrations of chloroform produce a rapid failure with, however, a rapid recovery on removal of the vapor. According to Hammouda and Wilson (1933) afferent impulses from the upper air passages diminish the depth of inspiration and prolong the first phase of expiration. Resistance to inspiration is shown to cause a decrease in depth and an increase in duration of the inspiratory phase of the cycle. Resistance

to expiration about equal to that in the normal air passages abolishes the expiratory pause, the presence or absence of which is therefore dependent on the extent of the functional resistance to the exit of air offered by the upper air passages.

In addition to those so far considered, visceral afferent impulses also arise in the aorta and the carotid arteries. These impulses arise from receptors of two types, one sensitive to pressure and the other to chemical agents. According to Heymans, Bouckaert and Regnier (1933) stimulation of the pressure receptors results in a change in the rate and amplitude of respiration. Bronk and Stella (1932) by recording the afferent responses in single fibers of the depressor nerve have shown that on activity the pressure end-organs develop a train of impulses following one another with a high degree of regularity. The discharge continues indefinitely at a frequency but slightly less than the initial value indicating thus that they, like the lung receptors, adapt very little. The frequency of the responses increases with increasing pressure in the sinus; with a drop in pressure the impulses cease. These pressure receptors are insensitive to variations in carbon dioxide and oxygen tension, and they have little if any direct effect on respiration. The second group of receptors, the chemical ones, respond to changes in the blood as found in asphyxia, acapnia and hypercapnia. The chemical receptors are the more influential in respiratory reflex effects. Gemmill and his associates (1934) have also shown that the response of the respiratory center to anoxemia is less rapid when the carotid sinus nerves are eliminated but that other mechanisms gradually take the place of these.

Bishop, Heinbecker and O'Leary (1934) have investigated the effect of stimulating the central end of the depressor nerve and have found that on stimulation of the depressor no immediate respiratory effect is obtained, but after fifteen or more seconds there may be a gradual increase, presumably due to depletion of the respiratory center when the systemic blood pressure falls. In contrast with this the increase in respiration due to vagus stimulation is very prompt if the frequency is high. Often the threshold for respiratory increase is the same as the threshold for the first action current of the nerve, but sometimes (Fig. 4) marked depression of blood pressure may be obtained via the vagus by high frequency stimulation, below threshold for a significant respiratory effect. In general then we may conclude that respiratory accelerator fibers are distinct from vasomotor depressor fibers. We do not know whether they are also distinct from pressor fibers, except that depressor nerves having an initial pressor action do not cause a corresponding increase in respiration when stimulated.

On stimulation of one vagus in lightly anesthetized rabbits an initial acceleration of respiration results. In practically all such animals an increase in strength and frequency reverses such an acceleration to a

slowing. It is very easy to stop the respiration if the depth of anesthesia is increased. With the degree of anesthesia which does not depress blood pressure, the results of progressively increasing stimuli are, first, increase of frequency and decrease of depth of respiration, then a reversal of these effects until the respiration may appear almost normal, except that a shorter pause occurs between expiration and inspiration, and finally a greater slowing and deepening until gasping results. This is usually followed promptly by struggling movements, but whether this is due to painful stimuli we have not ascertained; the latency of struggling is certainly much greater than that after similar stimulation of the saphenous, for instance. While this reflex has not yet been investigated in detail, the results would permit the inference that two groups of fibers are involved here also, with antagonistic functions, the accelerators lying in the larger fiber range, and the inhibitors in the small fiber range. A similar conclusion has been reached by Hammouda and Wilson (1935).

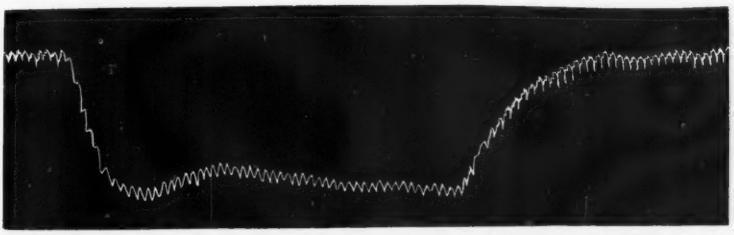

Fig. 4.—Record of blood pressure response to weak stimulation with induction coil 50/sec. of a cat vagus nerve. The small up and down movements indicate respiration. Note that there is little or no change in frequency or amplitude with the marked fall of blood pressure. Some change occurs after recovery of the blood pressure.

While the afferent impulses from the viscera are the more significant in the reflex modification of normal respiration, nociceptive impulses and others with an associated emotional content from somatic structures have a pronounced effect on the central respiratory neurons. These effects may be excitatory or inhibitory to both the inspiratory and the expiratory divisions of the center (Fig. 2). Proprioceptive impulses are constantly arising in the sensory endings of the intercostal and diaphragmatic muscles as well as in other muscles of the body. Their probable function is to coordinate the activity of the respiratory muscle groups and to aid in the adjustment of the respiratory response to the requirements of the body as a whole.

In summarizing our knowledge of the reflex modification of respiration by afferent impulses it is apparent that here, as in reflex activity generally, there are two central effects possible, excitation and inhibition. The afferents from the lungs are the most important in normal respiration. Under normal conditions the aorta and carotid respiratory reflexes

even though constantly active are not essential. They are to be regarded as a subsidiary mechanism helpful more especially in anoxemia. The somatic afferents help in the coordination of respiratory movements and in the accommodation of respiration to the respiratory needs.

It remains to speculate on the manner in which the impulses arising in the stretch receptors of the lung produce the effects they do. The impulses from these receptors at the same time inhibit inspiration and quicken its rate. The question is therefore raised as to whether there are one or two sets of fibers involved or whether the same type of peripheral end-organs have their fibers distributed to different central neurons. Adrian (1933) presents the interpretation that the fibers are of one type and affect one group of cells. Their action is supposedly to shorten the period of excitatory discharge of the neurons of the inspiratory center. This in turn permits a more rapid recovery of the neurons due to the shorter period of activity, and consequently their activity may be reestablished sooner than if they were active for a longer period thus leading to a quicker respiratory rate. When the depression by these fibers becomes still more marked, not only is the discharge period shortened but the frequency of the volley discharges is also lessened. Because it is not yet possible by experimental means to check directly the interpretation of Adrian, it is of interest to consider observations made on the manner of depression of a rhythmical ganglionic plexus in the median nerve cord of the Limulus heart by Hoffmann (1911) and by Heinbecker (1933). In the median nerve cord of Limulus there are among others two types of neurons, large pacemaker cells and smaller "motor" cells activating the contraction of the cardiac muscle. Vagus depression first lessens the duration of the activity of these motor neurons and then if of sufficient duration or intensity also slows the rate of periodic activity of the pacemaker cells. It seems reasonable to suppose that the respiratory center might function in a manner qualitatively similar to that of the rhythmical neuron mechanism of the Limulus heart nerve. In such an analogy two sets of pacemaker neurons would be assumed, one for inspiration and one for expiration, both subject to nervous and to chemical control. This pacemaker mechanism would control the rate of respiration. The duration of the respiratory phases would be controlled by the inherent activity period of the motor neurons on activation by the pacemaker cells. The duration of their activity would be subject to separate modification by afferent excitatory and inhibitory nervous influences as well as by local chemical conditions.

In such a system in normal respiration the afferent impulses from the stretch receptors in the lung would be considered to shorten the period of inspiratory motor neuron discharge. The increase in rate would result from chemical stimulation of the pacemaker cells because of the lessened air exchange. Excitation of the expiratory motor neurons would proceed coincidentally, but the order of effectiveness of central

summation on the inspiratory and expiratory centers would presumably be different. A somewhat similar difference in the effectiveness of temporal summation on the vasomotor centers has been described by Bishop, Heinbecker and O'Leary (1934, loc. cit.) who found that on increasing simultaneously the frequency of stimulation of the vagus pressor and depressor afferents the effect of the former gradually overbalanced that of the latter.

With stronger afferent stimulation from the stretch receptors in the lung both sets of cells of the inspiratory center would presumably be

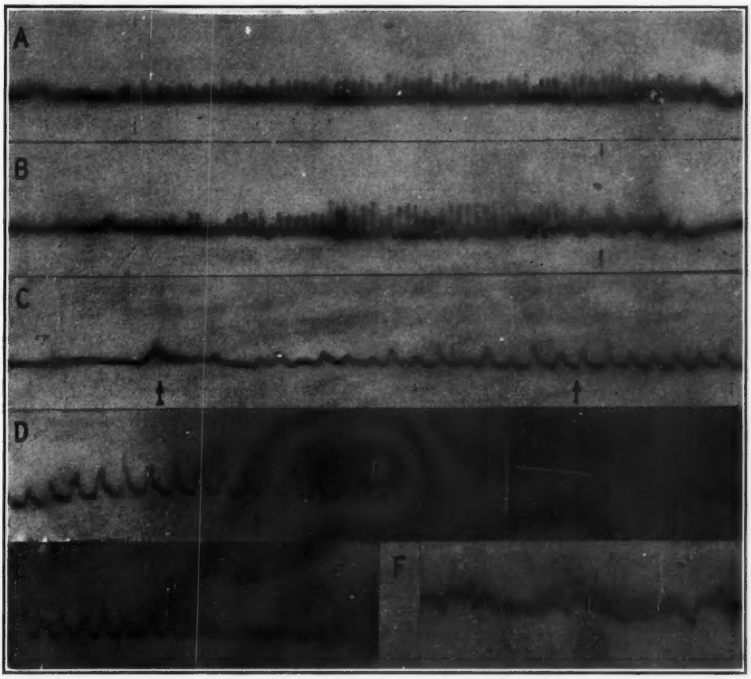

Fig. 5.—Records of potential changes in the phrenic nerve during inspiration.

A, The eighth inspiration after apnea induced by artificial ventilation with the chest open.

B, Fifteenth respiration.

C, Continuing in *D*, the tenth inspiration on a faster time line. Each inspiration occupies about four-fifths second, the individual waves being 90 per second. Arrows mark one-fifth second in *C* and *D*. In these records the volleys are unusually well synchronized. There appears to be little activity between volleys. The usual record from the phrenic shows maxima and minima at about this frequency. See Fig. 1 *B*, *C* and *D*. Presumably the individual fibers respond in each volley, thus the frequency of discharge of the center becomes the frequency of the volleys. The rabbit from which these records were made had been injected with Botulinus toxin but this has not been found to effect the respiratory center.

E, Continuing from *D* with faster time line.

F, Usual irregular type of response.

inhibited while those of the expiratory center would be excited. Such a dual function of similar receptor impulses is normally found in the con-

trol of muscular reflexes by reciprocal inhibition (Sherrington, 1906). Stimulation of the larger afferent fibers, alpha and beta groups, of the tibial nerve at the level of the knee results in an inhibition of the gastrocnemius and a contraction of the quadriceps extensor (O'Leary, Heinbecker and Bishop, 1935). The larger fibers in a muscle nerve are thus shown to initiate a reflex with a simultaneous double sign. The flexors at the knee have their reflex tone inhibited while the extensors are thrown into contraction by the same group of fibers.

So far our interest has been with the afferent side of nervous control. On the efferent side the respiratory muscles are innervated by fibers of ventral horn cells extending from the seventh nucleus to the lumbar cord. The activity of these ganglion cells has been studied by a number of investigators by recording the action potentials of the phrenic nerve (Fig. 5) and the nerves to the intercostal muscles. Bronk and Ferguson (1935) summarize their results as follows. The discharge of impulses from single motor nerve cells to the external and internal intercostal muscles of a cat has been recorded. (1) Each contraction is the result of a short burst of impulses. Variations in depth of intercostal respiration are a result of variations in the frequency of discharge from the individual nerve cells, the duration of their discharge and the number of nerve cells in action. (2) The rhythmic groups of impulses in the fibers to the external intercostal muscles are generally associated with inspiration; in the fibers to the internal intercostal muscles with expiration. The discharge in the interchondral part of the internal intercostal muscle is, however, synchronous with inspiration. (3) This rhythmic discharge of motor impulses continues when the volleys of afferent impulses resulting from respiratory movements are eliminated. The normal reciprocal character of the activity in the two sets of cells supplying the external and the internal intercostal muscles is likewise maintained in the absence of the rhythmic afferent volleys. (4) The relation between the frequency of discharge from the individual motor nerve cells and the intensity of stimulus has been observed by varying the degree of asphyxia. The impulse frequency increases with increasing asphyxia. (5) During respiratory failure of an animal the frequency of impulses from these cells increases to a high value. The discharge finally fails as the result of more and more impulses dropping out of the regular rhythm which thus becomes a series of scattered volleys.

We have now examined in some detail both the afferent and the efferent phases of the respiratory mechanism. It is pertinent at this stage to reiterate that the central neurons are strikingly susceptible to chemical influences. The degree of response of such central neurons is conditioned by their own chemical state. Their excitability is raised by an increased carbon dioxide tension and is lowered by a lessened one. In contrast the peripheral end-organs of the lungs are much less sensi-

tive to chemical alterations in their environment. The chemical receptors of the carotid sinus are, however, quite sensitive to changes in carbon dioxide and oxygen tension.

To complete this survey of the nervous mechanism of respiration we must consider briefly the intrinsic ganglia of the lung and their peripheral connections. The anterior and posterior pulmonary plexuses contain both sympathetic and parasympathetic elements. The parasympathetic elements are derived from the vagus nerves, the sympathetic fibers arise chiefly from the middle cervical and stellate ganglia. Their axons pass through the pulmonary plexuses to act on the intrinsic ganglia of the bronchial musculature. The ganglion cells of the plexuses are to be regarded as part of the intrinsic ganglionic mechanism of the bronchial musculature. Histologically they conform in structure to visceral ganglion cells generally. Their neurons are excited by sympathetic and parasympathetic fibers. It has been possible to demonstrate that the nonmyelinated fibers of the parasympathetic supply are those whose activity results in such bronchial constriction (Heinbecker and O'Leary, 1933). Stimulation of the sympathetic trunks results in bronchial dilation.

The independent activity of the intrinsic neurons has not been demonstrated, nor is it certain that they are reflexly activated during the widening and narrowing of the bronchi which occur during normal respiration. Similar changes in the caliber of the bronchi would occur from purely physical causes (Heinbecker, 1927). The intrinsic ganglia can be activated by the extrinsic nerves while the bronchi are at rest. Their response under such circumstances is more characteristic of nonrhythmical neurons than of rhythmical ones. The presence of the intrinsic neurons probably modifies the reaction of the bronchial musculature to certain hormones. This conclusion is based on the work of Armstrong (1935) who has recently shown that in the developing Fundulus heart, sensitivity of acetyl choline develops only after the intrinsic nerve cells enter the heart.

In this brief presentation of our conception of the nervous control of respiration we recognize a respiratory center with an inspiratory and an expiratory division. Each division consists of pacemaker cells which possess spontaneous rhythmic activity and motor neurons rhythmical only on excitation. The function of the pacemaker cells is to initiate rhythmic activity in the motor neuron. Both sets of neurons may be excited or inhibited by afferent impulses reaching them from the lungs, the blood vessels and the sensory receptors of the respiratory muscles and the body generally. The central neurons and certain receptors in the blood vessels are markedly sensitive to chemical changes in their external and internal milieu. The activity of the central motor neurons expresses itself through various motor mechanisms. One part

of this mechanism whose function is to alter the caliber of the bronchi acts through a peripheral nerve mechanism whose autochthonous activity is improbable.

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VARIATIONS IN THE AGES, SIZES AND PHYSICAL CHARACTERISTICS OF THE MAIN BRONCHI IN RELATION TO THEIR CLOSURE*

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IN HIS record of the first experimental total pneumonectomies, Gluck[1] makes the following prophetic statement,† "if, sooner or later, the surgical diseases of the lung shall be treated by resection, then animal experimentation again shall have given rise to the solution of an important problem." He remarks further that "an antiseptic procedure, the least possible tearing and crushing of the parts, and scrupulous hemostasis are the necessary preliminaries if the operation is to succeed." Thus it is seen that from the first (Gluck, 1881; Biondi,[2] 1882) it has been recognized that asepsis (in those early days, antisepsis) is requisite in experimental total pneumonectomy. Although the fear of infection of the pleura has persisted to the present day, a gradually acquired skill in the matter of closure of the bronchial stump both in animals and in human beings, whether or not the bronchial mucosa is clean or infected, has tended to restore confidence in an ability to control pleural infection, should it occur.

The experimental work on the closure of large bronchi has been ably reviewed in 1920 by Heuer and Dunn,[3] in 1934 by Heuer,[4] and more recently by Longacre[5] of Ried's clinic. Extensive series of total pneumonectomies in dogs have been performed with a low mortality rate by Willy Meyer[6] (1909), Kawamura[7] (1914) and Heuer and Dunn (1920), Adams and Livingstone[8] (1932), and Longacre (1935). With only six exceptions among ninety-three pneumonectomies, the closure of the main bronchus was secure in these groups of dogs. Possibly the group of Adams and Livingstone should not be included because the bronchi were stenosed by the application of silver nitrate to the mucosa before operation.

From all of this experimental work it is clear that in normal dogs, when sterile, atraumatic technic and meticulous hemostasis are attained, the main bronchus may be closed successfully by a variety of methods. These include simple ligaturing with strong silk; crushing and ligaturing with silk; crushing, ligaturing and inverting with interrupted silk sutures (Willy Meyer, Feiermann[9]); and inversion with silk without

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crushing (Longacre). In Longacre's series, the bronchial tree was frequently infested with virulent organisms, but in spite of this he was able to close the main bronchus soundly by inverting it with silk sutures which were carefully kept from penetrating the mucosa. Due credit should be given to Longacre for this achievement; this is quite a different matter than to close the main bronchi of normal dogs, where I found, as did Heuer and Dunn, that the mucosa was sterile in all cases in which cultures were made.*

It is striking that in all the successful series in animals, with or without infection in the bronchial tree, silk or some other strong, nonabsorbable material has been utilized for suturing or ligaturing. In a few of his animals Biondi used Lister's chromicized catgut with success, but others who have tried it have been unsuccessful except in a few individual dogs (Robinson and Sauerbruch,[10] 1909, Bettman,[11, 12] 1924, 1928, Longacre, 1935). Nevertheless, in two successful pneumonectomies which have been performed recently in children, aged five and seven years, for chronic bronchiectasis, Graham[13] used catgut, without drainage, and with primary union. He cauterized the mucosa distal to the tie with phenol and alcohol, and sewed over the end of the bronchus with catgut. With these two exceptions, so far as I am able to learn, catgut has not been employed successfully in human beings without the formation of a fistula.

An examination of Table I shows that in the successful cases of total pneumonectomy published so far, with only one exception (Graham and Singer[16]) silk has been used, no matter whether the technic has been by isolation and closure of the structures of the hilum individually, or by tourniquet and mass ligation. This in itself does not prove, of course, that silk is the preferable material. Rienhoff[17, 18] in one published case has sealed the isolated bronchus successfully and permanently with silk, and with primary union. Overholt[21, 22] has closed the bronchus and vessels by transfixion and ligature with silk, followed by primary closure of the wall of the thorax, with success in three cases. In one of these, stenosis of the bronchus was almost complete before operation. In one additional case a *Staphylococcus albus* empyema occurred without a fistula, and in another a similar empyema occurred with a fistula.

It is of some interest to point out that in 9 out of the 15 successful total pneumonectomies which have been recorded, the patients were less than 25 years of age. Rienhoff's patient, aged 3, is the youngest, and Graham's, a male, aged 48, and Overholt's, a female, aged 59, are the oldest.

In an effort to learn, personally, something about the closure of large bronchi, I carried out a series of total pneumonectomies in dogs. In order to simulate to a certain extent the conditions which might be encountered in human beings, large, old dogs were used for the most part;

*One exception; in a single animal out of eight, pneumococci were grown.

TABLE I

TOTAL PNEUMONECTOMIES WITH RECOVERY

	SEX AND AGE	PATHOLOGIC CONDITION	METHOD OF CLOSURE	FISTULA
Nisson[14]	Female 12	Bronchiectasis, left.	Rubber tube around hilus above stricture. Several silk ties peripheral to this. Allowed lung to slough out.	Small one.
Haight[15]	Female 13	Bronchiectasis, left.	Separate mass ligatures of heavy braided silk for upper and lower lobe pedicles. Allowed lung to slough out.	From upper lobe bronchus only.
Graham and Singer[16]	Male 48	Carcinoma, left.	Temporary catheter on hilus. Pedicle crushed, severed with cautery. Mucosa thermocauterized. Stump transfixed, tied with doubled No. 2 chromic. Similar tie placed where catheter had been.	Occurred on ninth postoperative day.
Rienhoff,[17] — and Broyles[18]	Female 3	Fibroadenoma, left.	Cut cartilaginous rings at several points in circumference. Sutured mucosa with continuous No. 1 plain catgut. Sutured wall of bronchus with interrupted silk.	None.
Rienhoff,[17] — and Broyles[18]	Female 24	Carcinoma, left.	Upper lobe and main descending bronchi closed separately as above.	From upper lobe bronchus only.
Windsberg[19]	Female 12	Bronchiectasis, right.	Hilus cleared, transfixed and doubly ligated with braided silk. Vessels individually secured. Bronchial mucous membrane thermocauterized.	Small one.
Mason[20]	Female 13	Bronchiectasis, left.	Separate mass ligation of upper and lower lobe pedicles with heavy braided silk.	Two.
Mason[20]	Male 18	Bronchiectasis, right.	One stout braided silk ligature around hilus. No slough. Lobes removed with galvanocautery 30 days later.	Three small ones.
Overholt[21, 22]	Female 33	Carcinoma, right.	Divided denuded hilus between tourniquets. Carbolized stump of bronchus and closed it with multiple silk sutures. Ligated vessels separately. Closed pleura over retracted stump.	Staphylococcus albus empyema and fistula.
Overholt[21, 22]	Female 42	Carcinoma, left.	Divided pedicle between tourniquets. Carbolized stump and closed with mass transfixion ligatures of silk. Buried stump beneath mediastinal pleura.	None.
Overholt[21, 22]	Female 44	Abscess, left.	Same.	None.
Overholt[21, 22]	Female 28	Multiple abscesses, left.	Same with primary catheter drainage.	None. Stenosis nearly complete before operation.
Overholt[21, 22]	Female 59	Carcinoma, left.	Same without drainage.	None. Staphylococcus albus empyema.

and, with only six exceptions among thirty-one animals, the pneumonectomies were performed on the right side (Table II). Fifty-eight per cent, by weight, of the lung in the dog is on the right. Because of a conviction, which may be ill-founded, that any method which requires too much nicety and which is time-consuming will not eventually find widespread application in man, it was decided to proceed simply.

In the first 18 dogs on which the operation was completed, using positive pressure intratracheal ether-oxygen anesthesia, the vessels of the pedicle were individually ligated with silk and divided, and the completely isolated main bronchus was crushed with a half-length (Kelly) clamp and ligated with heavy braided silk (Deknatel, No. 6). The last dog in this group, No. 69, died of tension pneumothorax three days after operation, and at autopsy it was found that a crushed and fractured cartilage had perforated the wall of the bronchus proximal to the intact ligature. The accident warned against by Willy Meyer had occurred.

Immediately thereafter two dogs, one very large, but young, and one of medium size, were operated upon without crushing the bronchus. The healing was sound, but it was considered unlikely that this method would prove successful in the closure of the larger main bronchi of adult human beings, particularly when they were stiffened by fibrosis or calcification. On the other hand, it seemed apparent that the walls of a large bronchus might be softened considerably by gentle rolling between the fingers or by careful compression with a clamp, so that the resistance of the rings would be importantly reduced without running the risk of perforation.

This method of *compression* was used in the remaining eleven dogs of the series, eight of which were large and old. The compression was accomplished by a curved half-length (Kelly) clamp which was closed down only to the first notch. It was applied in several directions to each of the four or five cartilages between the carina and the upper lobe orifice. The bronchus was softened considerably in this way without fracturing the cartilages or damaging the walls of the tube grossly. Following the compression, the bronchus was ligatured tightly with strong braided silk, placing the knot on the posterior surface. The lung was then thrown over, and the same ligature was retied securely anteriorly. A Kelly clamp was placed 3 mm. distal to the ligature, and the bronchus was severed along the clamp with a sharp knife. Cultures were taken from the mucosa, and the untreated stump was dropped back into the mediastinum. The field was made clean and dry, and two interrupted sutures of fine silk were placed to close the pleura partially over the stump and the mediastinum.

Gross inspection of the healed bronchial stumps shows that they are narrower and more pointed following crushing than after compression. After two or three weeks of healing, the effect of crushing is seen in the

TABLE II

AUTHOR'S SERIES OF TOTAL PNEUMONECTOMIES IN DOGS

SERIES NUMBER	DOG NUMBER	LEFT OR RIGHT	BRONCHUS CRUSHED OR COMPRESSED	CULTURE FROM STUMP	CAUSE OF DEATH	TIME AFTER OPERATION	CULTURE FROM PLEURA AT AUTOPSY
1	50	Left	Crushed	------	Distemper	9 days	--------
2	51	Left	Crushed	------	Sacrificed	15 weeks	Hem. strep.
3	52	Left	Crushed	------	Undetermined	9 days	------
4	53	Left	Crushed	------	Sacrificed	12½ wk.	------
5	54	Left	Crushed	------	Sacrificed	9 weeks	------
6	55	Left	Crushed	------	Sacrificed	5 weeks	------
7	56	Right	Crushed	------	Sacrificed	4 weeks	------
8	57	Right	Crushed	------	Sacrificed	5 weeks	Hem. strep.
9	58	Right	--------*	------	Sacrificed	6½ wk.	--------
10	59	Right	Crushed	------	Acute pneumonia	2 days	--------
11	60	Right	Crushed	------	Exposure, -10° F.	2 days	Staph. albus
12	61	Right	Crushed	------	Sacrificed	9 weeks	Staph. aureus
13	62	Right	Crushed	------	Anoxemia	On table	--------
14	63	Right	Crushed	------	Sacrificed	2 weeks	Staph. albus
15	64	-----	--------	------	Anoxemia	On table	--------
16	65	Right	Crushed	------	Sacrificed	3½ wk.	--------
17	66	-----	--------	------	Anoxemia	On table	--------
18	67	Right	Crushed	No growth	Sacrificed	3 weeks	--------
19	68	Right	Crushed	------	Sacrificed	2½ wk.	--------
20	69	Right	Crushed	------	Tension pneumothorax; empyema	3 days	Nonhem strep.
21	70	Right	--------†	------	Sacrificed	6 weeks	--------
22	71	Right	--------†	------	Sacrificed	6 weeks	--------
23	80	Right	Compressed	No growth	Sacrificed	3 weeks	Staph. aureus
24	81	Right	Compressed	No growth	Sacrificed	3 weeks	--------
25	82	Right	Compressed	No growth	Sacrificed	3 weeks	--------
26	83	Right	Compressed	No growth	Ac. dilat. stom.	1 day	No growth
27	84	Right	Compressed	No growth	Acute empyema	5 days	No growth
28	85	Right	Compressed	------	Sacrificed	15 days	--------
29	86	Right	Compressed	No growth	Sacrificed	15 days	No growth
30	87	Right	Compressed	------	Sacrificed	11 days	--------
31	88	Right	Compressed	------	Sacrificed	10 days	No growth
32	89	Right	Compressed	------	Sacrificed	6 days	--------
33	90	Right	Compressed	Pneumococci	Sacrificed	5 days	Staph. albus

*Tied right upper and right main descending bronchi separately with Deknatel No. 1 braided silk (tensile strength, 3 pounds), without crushing or compressing.

†Tied main bronchus without crushing or compressing.

distortion and angularity of the cartilages proximal to the ligature. When no crushing or compression has been carried out, or when the bronchus has been simply compressed, the bronchus proximal to the tie is wide, round and smooth. On gross section I found that a portion of the braided silk was lying free in the bronchial lumen in 7 of the 31 specimens, and in many more it was immediately beneath the mucosa.

In this regard, it seemed to make no difference whether the bronchus had been crushed, compressed, or tied without decreasing its resistance. Before they were sacrificed, many of the dogs had had a rather persistent cough, especially when held upright, which may have been due to the extruding silk. In none of the specimens was there any tendency for the silk to pass toward the mediastinum. It seems likely that in time it would be coughed out, or it might have to be removed through a bronchoscope. In 8 of the 31 specimens there was a small round cavity or narrow space with dark, gelatinous walls in the center of the stump, just distal to the tie. A portion of the tie always lay within this cavity, and, when the braided silk had penetrated the mucosa, the contents of the space had discharged into the lumen. The cavities were shown on microscopic examination to be small abscesses which contained lymphocytes and phagocytes as well as polymorphonuclear leucocytes. They appeared rather chronic.

Thus it is seen that the healing, though sound from the point of view that leaks did not occur,* was imperfect about the ligature, which gradually extruded itself from its bed of sterile or infected necrosis into the lumen. There was, however, nothing in the specimens to indicate that either crushing or compressing interfered with healing in any way. It seemed certain that the tightness of the ligature and the tension of the rings proximal to it had caused the extrusion by pressure necrosis. More will be said about the healing over the ends of the stumps later on.

It now seemed desirable to measure the resistance of various human bronchi to closure by ligature, and further to determine how much this resistance would be reduced by crushing or compression. As autopsies were performed, the trachea and the main bronchi were removed in one piece, the diameter of each branch was measured, and the characteristics of the walls of the bronchi were noted. The apparatus which was used to determine the resistance to ligaturing is shown in Fig. 1. The trachea was clamped horizontally in space, and a strong braided silk ligature was attached to a rod immediately above it, then tied loosely in a single square knot around one of the main bronchi and finally attached to a flask below. A smaller flask, which with added lead shot weighed 50 grams, was tied to a fine silk cord and run at a right angle over a pulley to a probe, the smooth, slightly bulbous end of which measured 1.5 mm. in diameter. Shot and other weights were added slowly to the first flask until the probe was held in the bronchus for at least twenty seconds by the tie. When this test was carried out in exactly the same way for various bronchi, a comparative record was obtained, which appears in Table III.

It will be observed that very little strength is required to close the main bronchi of newborn children. Even up to the age of four years,

*In all the dogs, at autopsy, the thorax was filled with water, and air was forced into the trachea at a pressure of 40 mm. of mercury or over. With the exception of Dog 69, no air came through any of the stumps.

no more than 1,000 grams (2.2 pounds) is ever necessary. Practically, in these small children, the initial resistance is of little significance, not only because of the low figure, but because the walls of the bronchi are so close together. But in children of four years and over, and in the youngest adults up to twenty-five years, the initial resistance increases in some individuals to as much as 2,000 grams (4.4 pounds). Crushing decreases the resistance by about 40 per cent, compression by about 30 per cent. Inasmuch as it takes about 2,000 grams to tie the largest, toughest aorta, the initial resistance of the bronchi may be considerable, and any decrease in the strength necessary to make a tie in the main bronchi of adolescents and adults acquires importance.

Fig. 1.—Apparatus used to determine the resistance of human bronchi to closure by ligature.

In the adults between the ages of 26 and 45, the bronchi become still more rigid, and before they are crushed some of them demand a pull of over 3,000 grams (6.6 pounds) before they will hold the probe. After they are crushed the resistance is reduced by an average of 65 per cent. In several of the bronchi tested the rings were calcified, and they, naturally, were the ones in which crushing resulted in the greatest decreases in resistance. In this group between 26 and 45 years of age, the resistance was reduced by compressing on an average by 40 per cent. In the age group between 46 and 65, the cartilages were more often calcified, and resistances of over 3,500 grams (7.7 pounds) were not uncommon. But, on crushing, these resistances melted at times to as low as 500 grams (1.1 pounds), a reduction of almost 70 per cent, on the aver-

age. Compression, compatible in all probability with viability of all the structures of the bronchial walls, decreased the resistance in this group by about 40 per cent. In the age group above 65, the bronchi were softened by crushing as much as 75 per cent, and by compressing about 45 per cent.

The curves in Figs. 2 and 3 indicate graphically the great and important reduction in resistance which crushing or compression brings about in the bronchi in the age groups beyond adolescence. The factors which add to the resistance as age increases are: (1) the increase in thickness of the constituent parts of the wall of the bronchus, due to growth, especially the submucosa, the muscularis, the cartilage and the

TABLE III

SIZES AND RESISTANCES OF MAIN BRONCHI TO CLOSURE, ARRANGED IN AGE GROUPS (HUMAN AUTOPSY MATERIAL)

	NEWBORN-5	6-15	16-25	26-45	46-65	66 AND OVER
Number of specimens examined	14	4	3	11	12	7
Average diameter of trachea, in mm.	10	11.3	----*	20.8	21.5	22
Average diameter, rt. m. bronchus	8.5	10	17	18.1	20	18.5
Average diameter, lt. m. bronchus	7.1	8.7	14	15.5	17	16.6
Initial resistance to closure, rt. m. bronchus, gm.	724	742	1692	2095	2506	2574
Resistance, rt. m. bronchus, after crushing	407	---*	998	807	754	794
Resistance, rt. m. bronchus after compressing	491	530	----*	1232	1325	1475
Initial resistance to closure, lt. m. bronchus, gm.	622	690	1546	1667	2349	2930
Resistance, lt. m. bronchus, after crushing	390	---*	981	455	955	689
Resistance, lt. m. bronchus, after compressing	462	620	----*	1231	1541	1461

*Insufficient data.

adventitia; (2) the increase in the diameter of the tube; and (3) fibrosis of the tissues of the wall of the bronchus and calcification of the cartilages. I have made no attempt to measure accurately the thickness of the various elements of the bronchial wall at different ages, but it is evident on both gross and microscopic examination that growth occurs up to the time of full development. Increasing fibrosis and calcification of varying degrees are apparent grossly and microscopically in most autopsy specimens beyond the age of thirty, occasionally even earlier.

The thickness of the walls and the diameter of the bronchus are not affected appreciably by compression. The reduction in resistance is brought about almost entirely by the softening of the cartilages. In the human autopsy specimens, microscopic examination shows extensive damage to all the tissues after they are crushed with a Kelly clamp. This is particularly true when there is calcification of the cartilages. The cartilages fragment, and frequently break through the mucosa, but al-

most never through the adventitia. This is the reason, in all probability, that, even though the bronchi in the first 18 dogs of my series were thoroughly crushed, there was perforation in only one. The smooth muscle, glands, blood vessels, nerves and fibrous tissue are torn in many places by crushing, but, between the tears, the structures show surprisingly little damage. The mucosa is destroyed completely down to the basement membrane. Following compression, the sections show practically no changes except occasional fragmentation of cartilage cells in the center of the ellipse, and the breaking up of the mucosa in places.

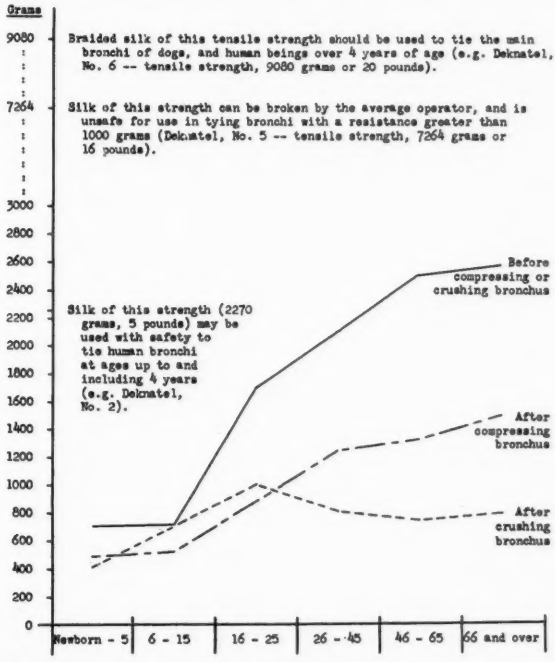
Grams
9080
Braided silk of this tensile strength should be used to tie the main bronchi of dogs, and human beings over 4 years of age (e.g. Deknatel, No. 6 -- tensile strength, 9080 grams or 20 pounds).
7264
Silk of this strength can be broken by the average operator, and is unsafe for use in tying bronchi with a resistance greater than 1000 grams (Deknatel, No. 5 -- tensile strength, 7264 grams or 16 pounds).
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Silk of this strength (2270 grams, 5 pounds) may be used with safety to tie human bronchi at ages up to and including 4 years (e.g. Deknatel, No. 2).
Before compressing or crushing bronchus
After compressing bronchus
After crushing bronchus
Newborn - 5
6 - 15
16 - 25
26 - 45
46 - 65
66 and over

Fig. 2.—Resistance to tying of human right main bronchus at various ages; silk suitable for tying bronchi.

The other tissues show no damage. Compression of the calcified bronchi causes fractures of the cartilages, but never more than a slight break in the mucosa. In no case did compression cause fractured cartilages to penetrate the adventitia, which is most important.

Examination of the autopsy specimens does not indicate, of course, how the bronchi would heal. However, sections from the dogs, killed at varying intervals after operation, show that neither crushing nor compression, with tight ligaturing, prevents repair of the bronchial stump at approximately the same rate as that at which an artery is healed, or a gastric or abdominal wound becomes solid. In other words, in

sections cut longitudinally through the stump, there is active proliferation of young fibrous tissue over the end of the stump by the sixth day. Between the two bundles of silk fibers lies a thick, double layer of compressed structures from which the mucosa alone has disappeared. The silk lies between cartilages which are more or less disarranged, but which stain well, with few exceptions, both proximally and distally to the tie. Just lateral to the silk is some fibrin in which are a few lymphocytes and occasional polymorphonuclear leucocytes. In the center of the stump, distal to the tie and proximal to the cap of young fibrous tissue, is an area of aseptic necrosis which is more or less complete. Bits of silk are seen in the periphery of the stump with a few lymphocytes and polymorphonuclear leucocytes around them. Proximal to the tie, the mucosa

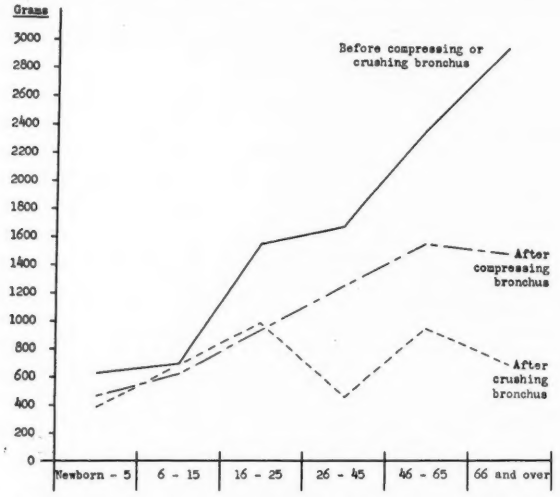

Fig. 3.—Resistance to tying of human left main bronchus at various ages.

dips down toward it, but disappears where the compression of the ligature has destroyed it. In the more reactionless stumps this picture is the same in all essentials whether the bronchus has been crushed and tied, compressed and tied, or simply tied.

After two weeks the healing is very solid over the end and sides of the stump. There is a thick pad of well-vascularized connective tissue in which foreign-body giant cells have appeared around bits of silk. This bulwark of fibrous tissue is heavy and well nourished whether or not there is an abscess about the ligature in the center of the stump, and whether or not the bronchus has been crushed or compressed. Crushing or compressing does not seem to have had any deleterious effect on healing in any sense. The only difference which I can make out between the healing of the crushed and that of the compressed bronchi, and this is purely architectural, is that, in the latter group, the lumen of the

bronchus widens out more rapidly proximal to the tie. This is evidently due to the tension of the ring which lies immediately above the ligature, and results simply in a broader stump.

After compression, the maximum resistances of the bronchi, beyond the age of 4, lie between 1,000 and 2,500 grams (2.2 and 5.5 pounds) as age advances. When tying against a resistance under 1,000 grams, the sense of touch in the human hand is able to detect with fair certainty that a solid tie has been made. Therefore, below this figure, somewhat lighter silk may be used with safety (e.g., Deknatel Nos. 1 to 3, for newborn infants to children of 4 years). (See Fig. 2.) The operator can be sure from his tactile sense that the lumen is soundly closed, and he can be certain of this before he breaks a tie. However, when the resistance is greater than about 1,000 grams, the sense of touch is no longer reliable. Silk may bind in areolar tissue, even when waxed, and the tie may seem secure when the lumen is either actually or potentially open. Therefore, it is necessary to use a tie which is so strong that the operator cannot possibly break it (e.g., Deknatel No. 6, tensile strength 20 pounds). He can then exert, if he is powerful, a force of about 16 pounds (7,264 grams) on it, which is more than sufficient to close any bronchus which has been compressed. Whereas any aorta may be cut in two, out to the adventitia, by a braided silk tie placed on it with a force of 3,000 grams, a normal bronchus of any size will withstand, without cutting, a pull of 7,000 grams or over (which is about the greatest traction any surgeon can exert in the position in which he operates).

In the dogs, I used Deknatel No. 6 silk, and always tied as tightly as I could. The stumps show that such a powerful constriction of the tissues is undesirable in that it results in pressure necrosis with extrusion of the silk into the lumen. However, I would be fearful that complete closure of the lumen would not be attained if an attempt were made to tie gently as one does for a blood vessel. In tying with a maximum pull the operator chooses the lesser of two evils, and the worst that he can do apparently is to cause extrusion of the silk, and spontaneous or bronchoscopic expulsion several weeks later.

DISCUSSION

It is possible that, in the presence of gross or virulent infection of the mucosa or peribronchial tissues, the tie, when placed with great force, might cause trouble. Further work, similar to that of Longacre on pneumonectomies in the presence of pulmonary suppuration, must be done to determine whether or not compression and tight ligaturing with strong braided silk is a satisfactory method of closure for infected bronchi. It is of some significance perhaps that the bronchial stumps did not leak at the site of the ligature in any of my dogs in spite of the fact that several of them had subacute and chronic empyema during the time of healing (Dogs 51, 57, 61, 63 and 80), and I would predict that the method of compression and ligature will be found applicable even in the presence

of infection. It seems likely that under these circumstances the bronchial mucosa should be sterilized with phenol and alcohol or, possibly, by the actual cautery (Archibald,[23] Graham, Overholt).

Although experiments on dogs show that neither crushing nor compression is necessary to the closure of their main bronchi, it should be recognized that even the bronchus of a very large, old dog does not correspond in resistance to that of an adult human being. Measurements by the method used for human autopsy material show that bronchi of the large, old dogs correspond in resistance to those of human beings aged 12 to 15 years. The probable importance of the reduction in resistance of the bronchi in human beings, as shown in Figs. 2 and 3, becomes apparent, for it is only by means of crushing or compression that ties can be made certainly and permanently occlusive.

If the cartilages proximal to the ligature or line of suturing could be severed, as described by Rienhoff, without danger of perforating the wall of the bronchus, the resistance of the tube could be reduced greatly. But I have not been able to do this, without actual or potential perforation, in many of the adult autopsy specimens, and it seems likely that this procedure, as well as the method of crushing, will be found too dangerous for ordinary use.

On the ground that the step would be more likely to result in extrusion of the silk into the lumen, it would seem preferable not to use a transfixing suture in the main bronchus. However, the most successful closures in adults to date have been those of Overholt, who has used this method. Possibly the extrusion of the silk will not be found to be an important feature in the human cases, but in dogs it occurs in a high percentage of instances when braided silk is tied tightly about the bronchus.

I have found nothing in my experiments to indicate that it is of importance to pay particular attention to preservation of the bronchial arteries, a point stressed by Longacre. The areolar tissue of the mediastinum, the repairing stumps of the adjacent pulmonary vessels, the pericardium and the pleura, all appear to contribute to the rapid throwing out of a bulwark of well-vascularized connective tissue which rather quickly caps the end and sides of the damaged bronchus. If sound closure of the bronchus has been attained, retraction of the stump into the mediastinum is obviously of great advantage to healing, and the same can be said about covering the mediastinal wound with pleura.

CONCLUSIONS

I hesitate to draw conclusions from any of the foregoing material, but it seems reasonable to suggest that:

1. Main bronchi in children of four years or under may be tied safely, without crushing or compression, with silk or chromicized catgut of a tensile strength of about 3 to 10 pounds (e.g., Deknatel braided silk, Nos. 1 to 3, or chromic catgut, Nos. 0 to 2).

2. Before ligaturing, the bronchi of children above the age of four, and of adolescents and adults, should be compressed carefully with the fingers or a fairly broad clamp until their resistance is reduced approximately 50 per cent. The compression may be sufficient to fracture calcified cartilages in a few places, but the cartilages should not extrude through the submucosa and mucosa into the lumen of the bronchus.

3. After compression, the bronchi of individuals over the age of four should be tied with braided silk which is heavy enough so that the operator cannot possibly break it (e.g., Deknatel No. 6). Catgut should not be used, because, under the constant strain caused by the remaining tension of the cartilaginous rings proximal to the ligature, the tie is likely to soften and allow the walls to spring apart before healing at the end of the stump is sufficiently strong to prevent perforation.

4. When the mucosa is grossly or potentially infected, the same technic should be followed, except that the mucosa distal to the tie should be treated with phenol and alcohol. (However, the proper treatment in the presence of infection of the mucosa should be further investigated.)

5. Whenever it is necessary to make a mass ligation of the hilus, braided silk with a tensile strength of at least 20 pounds (9,080 grams) should be used (e.g., Deknatel No. 6).

6. When a technic which corresponds to Brunn's[24] for lobectomy is adopted for pneumonectomy, the deepest continuous suture or the deep interrupted sutures should be of strong braided silk (e.g., Deknatel No. 3, tensile strength 10 pounds), and the outer sutures should be of catgut.

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TUMORS OF THE CHEST DERIVED FROM ELEMENTS OF THE NERVOUS SYSTEM*

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THE work of Cushing and Bailey, Penfield, and others in classifying the tumors of the central nervous system according to the histogenesis of their type cells has been of great aid in establishing the pathologic diagnosis, the prognosis, and, to a certain degree, in the treatment of these lesions. A consideration of the embryologic development of the central nervous system proved to be the key to a more complete understanding of its neoplasms.

The purpose of this paper is to trace the derivation of the various elements composing the nerves and ganglions of the thorax, and, having then made out a geneologic table, so to speak, to fit into it typical examples of the various tumors arising in connection with these structures.

The thorax contains nerves of both the somatic and the autonomic systems, and, in addition, in the paravertebral ganglionic chain and in the cardiac and pulmonary plexuses, ganglion cells in profusion. We must, therefore, trace the embryologic development of the autonomic nerves and of their ganglions, of the somatic nerves and the nerve sheaths, and, in addition, for the sake of completeness, of the connective tissue elements contained in these structures in the adult.

In the embryo the autonomic ganglions are derived from the medullary epithelium by way of the neural or ganglionic crest cells which migrate outward to the sites of future ganglions and plexuses where they receive fibers from the spinal cord and brain stem and whence they in turn send out fibers to the various structures which they supply. In the course of this process the cells undergo a series of developmental changes from primitive undifferentiated cells through the cell types spoken of as sympathicoblasts (sympathigonia) and neuroblasts, to the adult type of sympathetic ganglion cells. The distance over which this migration takes place is so great as distinctly to favor faulty development resulting in "rests" of immature cells potentially capable of proliferation. The various steps in this maturation are set forth in Fig. 1.

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The intercostal nerves are composed of fibers of cells in the gray matter of the cord or in the ganglions of the posterior roots, both derived from the medullary epithelium—the latter by way of the neural crest.

The sheaths of the peripheral nerves, three in number—the myelin sheath, the sheath of Schwann, and the connective tissue sheath—are of quite different anatomic origin and physiologic significance. The myelin sheath belongs properly to the axis cylinder and has a similar derivation. The sheath of Schwann, on the other hand, develops from the medullary epithelium by way of the ganglionic crest, while the connective tissue sheath (Henle's sheath) is of mesodermal origin and composes the endoneurium and perineurium.

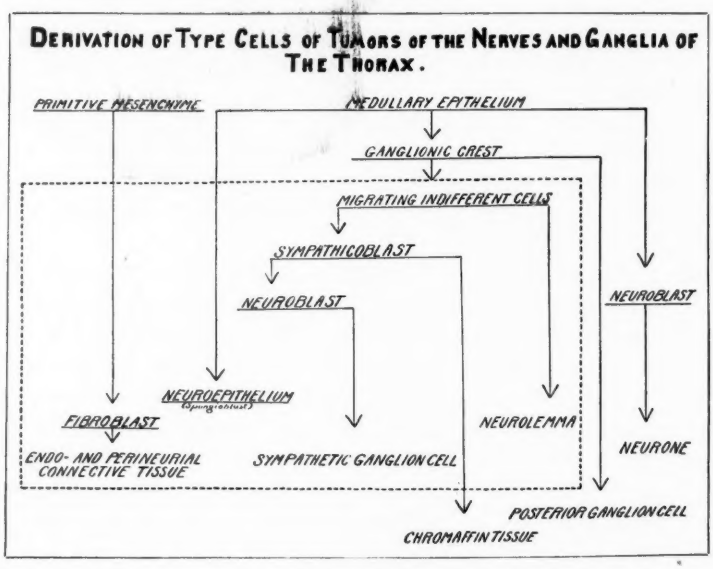

Fig. 1.—Derivation of type cells of tumors of the nerves and ganglia of the thorax.

The sympathicoblasts (sympathigonia) give rise not only to the cells of the sympathetic nervous system, but also to the chromaffin tissue of the adrenal medulla, the carotid and coccygeal bodies, and the "Gelbenzellen" of the intestinal tract.

These then are the precursors of type cells to be found normally as constituents of the adult nerve structures in the chest. As previously indicated, however, their process of development is extremely complicated; and one might expect that occasionally cells would be carried into the chest of a kind also derived from the medullary epithelium but normally found only in the central nervous system or its immediate outpouchings, such as the retina. Only on such an hy-

pothesis can we explain the presence in the chest of a tumor, such as a neuroepithelioma, composed of primitive spongioblasts.

The various elements of the ganglions are bound together by connective tissue, and the nerve trunks themselves contain a considerable amount of fibrous tissue forming the endoneurium and perineurium. This tissue develops from the primitive mesenchyme and may give rise here as elsewhere to any of the tumors of the fibroblastic series.

Having set up a chart of derivation of the various elements making up the nerve structures to be found in the thorax, if one draws a line as in Fig. 1, it is found to enclose the type cells of practically all the tumors derived from such elements which have been reported as occurring in the chest wall or within the thorax. Moreover, the higher the type cell of which the tumor is composed lies in the chart, the more malignant is the tumor.

As has been emphasized by Foot and others, the accurate diagnosis of these various types of neurogenic tumors requires methods that stain nerves and their surrounding structures specifically. These methods and their application in differentiating such tumors are presented in a paper by Foot in the *American Journal of Clinical Pathology* for January, 1936.

Let us now consider the clinical and pathologic aspects of examples of such tumors, beginning with those composed of the more adult type of cells, which are found more commonly in the chest. These are usually benign and include the ganglioneuromas, Schwannomas, or neurinomas, and the neurofibromas. They have been recognized more often in adults, but some, particularly the ganglioneuromas, are being reported with increasing frequency in children.

The clinical picture in this group may give little or no indication as to the exact type of tumor present. Many of these tumors undoubtedly remain asymptomatic and are picked up only during the course of routine x-ray examination of the chest; some begin to give symptoms during the patient's convalescence from a respiratory infection such as pneumonia, while in others the initial symptoms are those of a complicating pulmonary infection. In still others definite symptoms are present early in their development. In most of these the presenting symptom is pain, often with characteristic radiation, or some other symptom of pressure on nerve structures such as a Horner's syndrome, hoarseness, or an irritative cough. Large tumors may produce symptoms and signs of pressure on other mediastinal structures with dislocation of the trachea or compression of the larger bronchi. Perhaps, however, because of their slow growth and because many are discovered before attaining great size, serious mediastinal pressure symptoms are not very common with this type of tumor.

The x-ray examination shows a benign tumor with a shadow of even density and a smooth curved outline, located most often in the paravertebral "gutter" and in the upper part of the chest. Again, except on the basis of chance, no differential diagnosis is possible beyond that of a benign tumor, but in those cases, usually of neurofibroma, in which the tumor arises from one of the intercostal nerves more or less distant from the intervertebral foramen, there may be some pressure erosion of the rib margins above and below the point of origin.

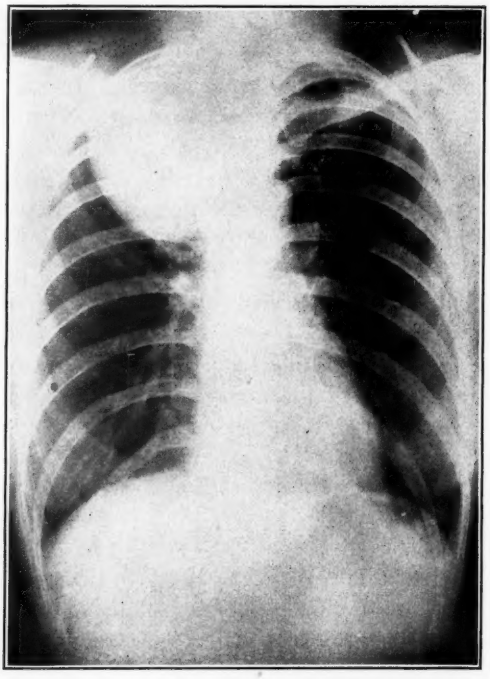

Fig. 2.—X-ray picture showing typical picture of benign tumor of the mediastinum of neurogenic origin, in this case a myxoneurofibroma.

The clinical picture may, perhaps, best be summarized by the description of a typical case.

A woman, thirty-nine years of age, was admitted to the New York Hospital on Feb. 7, 1934, having noted the appearance of a typical Horner's syndrome fifteen years previously. For ten years she had also suffered from what she described as sudden attacks of bronchitis with an unproductive cough and during the past year had had periodic attacks of vertigo. Physical examination revealed dullness and absent breath sounds over the upper half of the right chest, and x-ray examination (Fig. 2) showed a large tumor of even density with a clearly defined and curved margin occupying the upper portion of the right chest, slightly compressing the trachea. This tumor was removed on May 3, and proved to be a myxoneurofibroma

(Fig. 3). The patient recovered uneventfully, but, as was to be expected from the period of time over which it had been present before operation, still has the Horner's syndrome.

The typical neurofibroma is that seen in von Recklinghausen's disease—a tumor arising from a nerve and containing any or all of the constituents of the nerve trunk. Such tumors are thought to spring primarily from the perineurial or endoneurial fibrous tissue and are sometimes very largely fibrous, or there may be a concomitant overgrowth of nerve fibers producing a mixed picture. In some the fibrous tissue may undergo degeneration with the production of myxomatous tissue, as in the case outlined above. In addition, malignant changes may occur resulting in sarcoma.

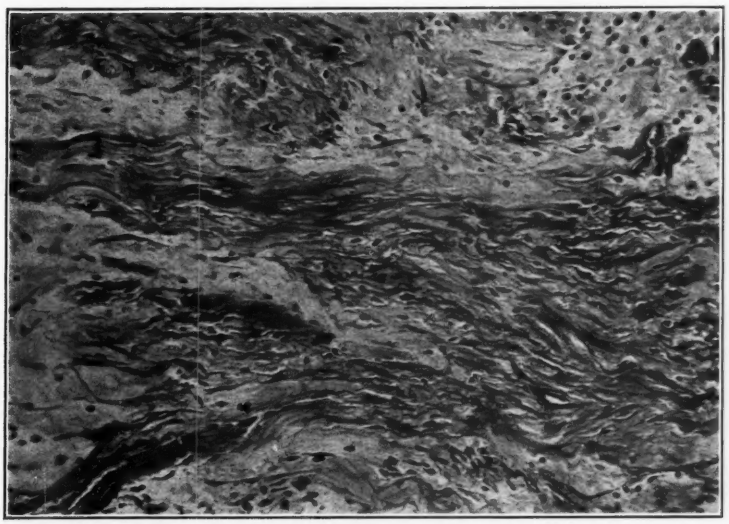

Fig. 3.—Myxoneurofibroma. Photomicrograph of tumor from the patient in Fig. 2, showing a bundle of nerve fibers together with fibroblasts and myxomatous tissue.

In the chest, in by far the greater number of reported instances, the tumor has been solitary, but in some the nerves of the thorax have shared in a typical widespread involvement of the peripheral nerves in the neurofibromatosis of von Recklinghausen's disease.

The histories of many of the cases of ganglioneuroma or lemmoma (Schwannoma-neurinoma) have been quite similar to the above, variations seeming to depend more upon the site of origin of the tumor and its relation to the mediastinum than upon its intrinsic make-up.

GANGLIONEUROMA

Most of the ganglioneuromas which have been reported have been found outside the thorax, in the neck or abdomen; but, as chest tumors are being attacked with greater frequency, careful study of those re-

moved has resulted in finding ganglioneuromas in the thorax in increasing numbers. Thus, seventeen instances have been reported during the past seven years. These tumors may be found in children or in adults, and while usually benign, may show evidence of malignancy, either due to malignant degeneration of one of their components or because they occasionally contain cells embryologically less mature than the adult type of ganglion cell characteristic of the true ganglioneuroma.

The true ganglioneuromas vary considerably in size, the reported tumors ranging from the size of a hen's egg to that of a child's head or larger, in one of Sauerbruch's cases measuring $17 \times 12 \times 8$ cm. They are well encapsulated and usually of firm consistency, but in some

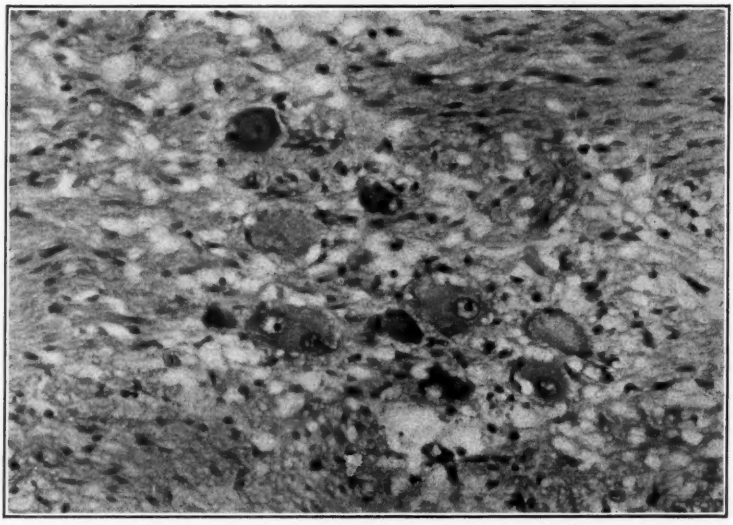

Fig. 4.—Photomicrograph of a typical ganglioneuroma containing nerve fibers—rather loosely arranged fibrous tissue and ganglion cells.

instances are composed of a firm outer shell enclosing a mass of softer tissue. The cut surface is gray and glistening and appears to be relatively avascular, with some lobulation. Microscopically one sees typically rather coarsely arranged, fibrous tissue mixed with strands of medullated and nonmedullated nerve fibers with the nonmedullated fibers usually the more numerous. Intermingled with these elements are found multipolar ganglion cells varying in number in different tumors, and many of them showing signs of degenerative changes such as vacuolization, etc. (Fig. 4.)

In addition, tumors are encountered containing numerous ganglion cells but in which the greater part is composed of fibrous tissue. These are more properly spoken of as ganglioneurofibromas; since they cor-

respond with and run a clinical course quite similar to the ordinary neurofibromas. Indeed, they perhaps differ from the latter only because their site of origin is such that they include numerous ganglion cells.

More or less typical of this group of tumors is the case reported by Sophian.[1]

CASE.—Girl, aged seven and one-half years, was admitted to Roosevelt Hospital, Nov. 1, 1930, with complaints of cough and fever, of one and a half years' duration. These symptoms occurred in attacks in which the patient coughed until breathless, raising a small amount of sputum. There was no vomiting, no night sweats, no loss of weight. The past history was negative. She had been immunized against diphtheria and vaccinated against smallpox. The present attack began two days before admission and was accompanied by fever, ranging from 99° to 104°. On examination the only positive findings were dry, squeaking râles over the entire chest. There was no evidence of consolidation.

X-ray examination of the chest taken November 3 demonstrated a circular shadow of increased density occupying the extreme upper portion of the right lung field. The trachea was displaced to the left. A lateral view showed an anteroposterior diameter greater than that found in the posterior anterior film.

Physical examination in this zone showed increased dullness and decreased breath sounds high on the posterior aspect of the right side of the chest, beginning one inch below the spine of the scapula and extending over the apex of the lung to the second interspace anteriorly.

Blood examination revealed red blood cells 4,300,000; hemoglobin 65 per cent; white blood cells on several examinations varied between 6,300 and 16,700 of which, in the latter count, 81 per cent were polynuclear neutrophiles.

Nov. 14, operation was undertaken under intratracheal anesthesia by Dr. J. I. Russell. A large hypodermic needle was first introduced into the back over the estimated position of the tumor, and an attempt was made to aspirate, in order to exclude the presence of a cyst. No material could be obtained except a small amount of blood. Following this, an incision was made obliquely from the first rib near the midline posteriorly, downward and outward across the third rib. The second, third and fourth ribs were exposed after separation of the trapezius and rhomboid muscles, and the third rib was resected. The tumor was exposed and found to be extrapleural. On account of its size it was found necessary to resect the second and fourth ribs. The incision was then enlarged through the periosteum and subcutaneous tissue and the lung exposed. The tumor appeared to be about 3½ × 2 inches and encapsulated. By gradual finger dissection it was brought into the wound and raised from the mediastinal cavity. A small pedicle was found attaching it opposite the body of the second dorsal vertebra. This was divided. There was very slight bleeding. The pleura was torn at one point and immediately repaired. The lung did not collapse at any time, even when the positive pressure was withheld. The deep parts were closed with continuous catgut, the muscles with interrupted catgut, and the skin with interrupted sutures of silk which were removed on the sixth day.

Pathological Examination.—The specimen was ovoid, weighed 150 gm. and measured 10 × 7 × 6 cm. The color was yellowish pink, and the capsule fibrous with a projection on one broad surface which came to a ragged point where an attachment had been cut. A rounded lobulation was noted on one surface. On section the cut surface was pinkish gray and showed fibrous markings, like a fibroma. The consistency was resilient, and in the central portion occurred a small linear hemorrhage (possibly caused by the needle puncture).

Microscopic examination revealed a stroma of small spindle cells scattered among a considerable amount of fibrillary substance. Very striking were the numerous large rounded and stellate cells which stained deeply with hematoxylin and presented rounded nuclei, frequently with one prominent nucleolus. These cells appeared sometimes grouped among delicate fibrillae and surrounded by trabeculae of denser supporting stroma. Some foci consisted of non-nucleated rounded or tubular masses 20 to 30 microns in diameter staining with eosin. By the Weigert method these appeared to be myelin. There were also some foci of fat with necrosis, calcification and giant cell formation of the foreign body type. In such zones could be seen clusters of lymphocytes.

Diagnosis.—Ganglioneuroma.

Postoperative Course.—X-ray examination November 25 showed a definite fluid level in the cavity from which the tumor had been removed. The heart and trachea were in the midline. December 19, the shadow in the right upper lung field was considerably reduced and the fluid line was absent. The shadow assumed an irregular outline and diminished in size on subsequent examination Jan. 3, 1931. The patient was discharged in excellent physical condition on that date. The postoperative course was smooth with fever diminishing after ten days and remaining normal. On subsequent examinations the physical condition was found excellent. X-ray examination April 29, 1933, showed no evidence of recurrence, the lung tissue filling in the right apex completely.

The ganglioneuromas, since they arise in intimate connection with one of the sympathetic ganglions, may remain confined to the chest, or, if they spring from one of the upper thoracic ganglia, may protrude through the superior thoracic aperture into the neck. Rarely, however, they, as well as the neurofibromas and neuromas derived from the perineurium or nerve sheaths proper, if they arise in or near an intervertebral foramen, may grow both into the spinal canal and into the thorax, forming the so-called hourglass tumors. This characteristic they also share with the rarer malignant tumors of neurogenic origin, as well as with certain chondromas and sarcomas. Heuer[2] in discussing 64 cases of hourglass tumors, including 3 of his own, found that 37 had occurred in the thorax and of these, 21, or 56.8 per cent, were derived from components of the nerve structures.

In the hourglass tumors the symptoms and signs of compression of the spinal cord are usually more prominent than those attributable to the intrathoracic portion of the tumor. Indeed, in some of the reported cases the intrathoracic prolongation has been discovered only in the course of a laminectomy. Routine x-ray pictures, however, have demonstrated an intrathoracic mass in many cases, and the diagnosis is strongly suggested when the x-ray film shows an intrathoracic tumor in a patient with signs of cord compression.

NEURINOMA—SCHWANNOMA—LEMMOMA

Tumors arising from the cells of the sheath of Schwann have the gross characteristics of fibromas but present a different histologic picture. The Schwann cells are believed to arise from the neural crest, are thus of ectodermal origin, and form a specific stroma of the

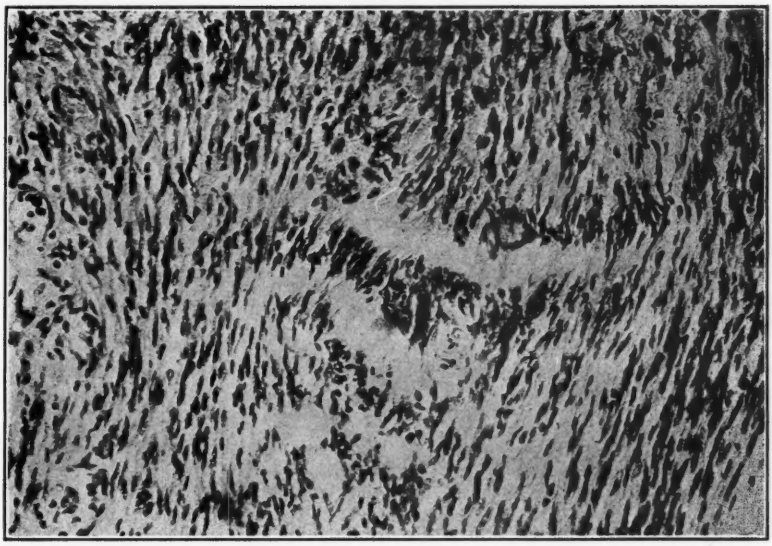

Fig. 5.—Photomicrograph of a neurinoma (Schwannoma) showing "palisading" of the nuclei typical of these tumors.

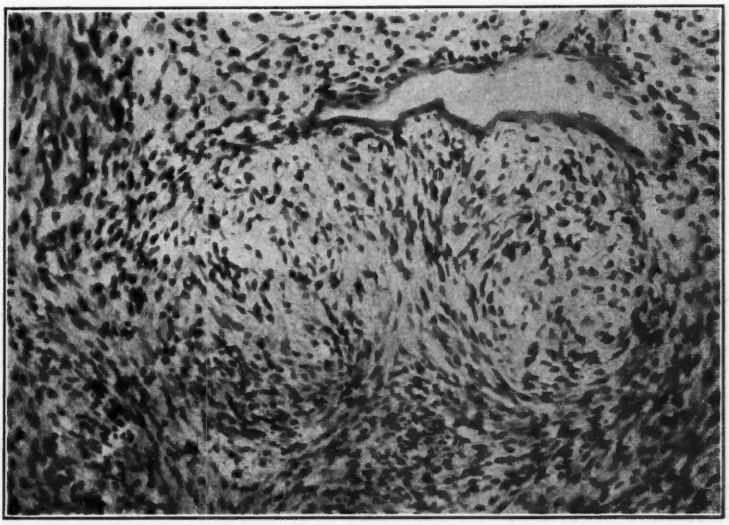

Fig. 6.—Photomicrograph of typical whorls of cells or "Verocay bodies" in a neurinoma (Schwannoma).

peripheral nerves, being considered by many as analogous here to the true neuroglia of the central nervous system. The typical neurinoma presents as a nodular, elongated enlargement of a nerve, or projects from it as a rounded mass. Microscopically two types can be distinguished, the one composed of elongated fusiform cells, often with many vacuoles giving a foamy appearance to the cytoplasm and with the nuclei arranged side by side, the so-called "palisading" (Fig. 5). In addition, whorls of cells may be present, resembling those seen in meningiomas, in neurinomas, known as "Verocay bodies" (Fig. 6). The second or Antoni type of neurinoma shows considerable mucoid degeneration and may be mistaken for myxoma.

These tumors have been less commonly reported from the thorax than from the peripheral nerves and within the spinal canal. Many of the hourglass tumors, however, have been shown to be neurinomas. Three such cases are reported by Knutsson.[3] One of these from the Keys Clinic is outlined as follows.

The patient, a girl aged fifteen years, was admitted to the Gävle Hospital on Sept. 22, 1929, complaining of aching pains in her right leg, particularly in the region of the knee, of two months' duration. Lately she had also had pains in the back.

Examination showed diffuse tenderness on percussion of the cervical and lumbar spine. There was no rigidity of neck and no atrophy of muscles of the lower extremities. The Babinski reflex was positive on both sides. The patellar and Achilles reflexes were exaggerated. Both patellar and ankle clonus were present. The abdominal reflexes were absent. On examination of the chest there was marked dullness over the left apex, but otherwise nothing of note.

Lumbar puncture May 25, 1930, showed a pressure of 150-170 mm. and the Queckenstedt test showed signs of some obstruction. The Nonne and Pandy reactions were positive.

Myelography with lipiodol was carried out on June 15, at which time the lipiodol moved unhindered as far as Th. IV. At this point there were signs of obstruction.

Repeated x-ray examinations of the thorax while the patient was in the hospital showed a persistent soft shadow, the size of an orange, in the left apical region. This had an evenly rounded lower border. In the medial part of the second rib and on the lateral part of the second thoracic vertebra there was some superficial pressure atrophy. Preliminary irradiation did not diminish the size of the tumor.

Operation was performed on June 27, 1930. Free exposure of the arches did not reveal any caries, nor was any detected after removal of the arches of Th. II, Th. III, and the spinous process of Th. I. However, a tumor was seen extending a little under the arch of Th. IV, and up under Th. I. It was located on the left and dislocated the cord toward the right. The tumor was clearly covered by a thin membrane of the dura and was firm and nodular. It was removed piecemeal except for the upper and lower parts, which were removed in one piece. The cord was now exposed with the escape of some spinal fluid. On the left a portion of the tumor extended into the intervertebral foramen between the second and the third thoracic vertebrae. This was also removed.

The patient recovered fairly well after the operation, but x-ray examination six months later still showed some opacity in the left apex.

Pathologic Diagnosis.—Neurinoma.

These then are the tumors arising from elements of the nervous structures in the chest which are composed of the more adult types of tissues. As a rule they are benign but, like similar tumors elsewhere, may undergo malignant change. They make up certainly over 90 per cent of the thoracic tumors of neurogenic origin. It remains to discuss the relatively more malignant tumors.

One of these, the neuroepithelioma, is extremely rare in the chest; and, so far as we know, the tumor removed by Sauerbruch, which through his kindness I was able to study from the standpoint of its histopathology in Professor Rossle's laboratory,[4] is the only example of this tumor in the lung to be found in the literature. It is included, however, because of its significance in the histogenic series.

Neuroepitheliomas were first found in the retina by Flexner[5] in 1891, where they may occur as part of a more primitive type of tumor such as a medulloepithelioma, or may be found, as in the tumor in the chest, in pure form. The pure neuroepitheliomas are less malignant, as might be expected from their relatively more advanced position in the histogenic series, and their origin is best explained on the basis of cell inclusion occurring during embryonic life. Thus, in the retina, Wehrli[6] and Fuchs[7] have found similar structures with characteristic rosette formation in microphthalmia associated with developmental defects in the brain. A few of these tumors have also been found in the brain itself, one of the later reports being that of Bucy and Muncie[8] in 1929, in the cerebellum.

The neuroepitheliomas are composed of more or less columnar cells of irregular contour and with cytoplasm which stains indistinctly. The nuclei are round and take a deep stain. The cells tend to surround cavities forming the so-called rosettes by their radial arrangement. The cell borders form an internal limiting membrane around a cavity containing colloid or hyalin material. The internal end of the cells bear cilialike projections, while from the outer end there project taillike processes. The type cell of the so-called neuroepithelioma is really a primitive form of the spongioblast, and in the retinal and brain tumors of this variety other glial cell types such as astroblasts, astrocytes and oligodendroglia are found. The tumor removed from the lung by Sauerbruch, however, contained only spongioblasts.

The case history of Sauerbruch's patient was as follows.

The patient was a young woman of twenty-three years, who had enjoyed good health until the summer of 1927 when she suffered from pleurisy. In February, 1928, she had an hemoptysis and entered a sanatorium where diagnosis of tuberculosis was made and a shadow recognized in the right lung. In the few months previous to her admission to the hospital she tired easily and had slight dyspnea on exertion as well as some cough with occasional hemoptysis. Since 1927 she had numerous x-ray pictures of the chest, and over this period the shadow in the right lung increased slowly in size.

Physical examination on July 23, 1931, showed the following: slight dullness to percussion on the right extending from the paravertebral line to the midaxillary line below the angle of the scapula. Right lung showed normal resonance. There was a marked decrease in the breath sounds in the region of dullness. Elsewhere auscultatory findings were normal.

Operation under ether anesthesia was performed through a curved paravertebral incision on the right side; wide resection of the seventh and eighth ribs was per-

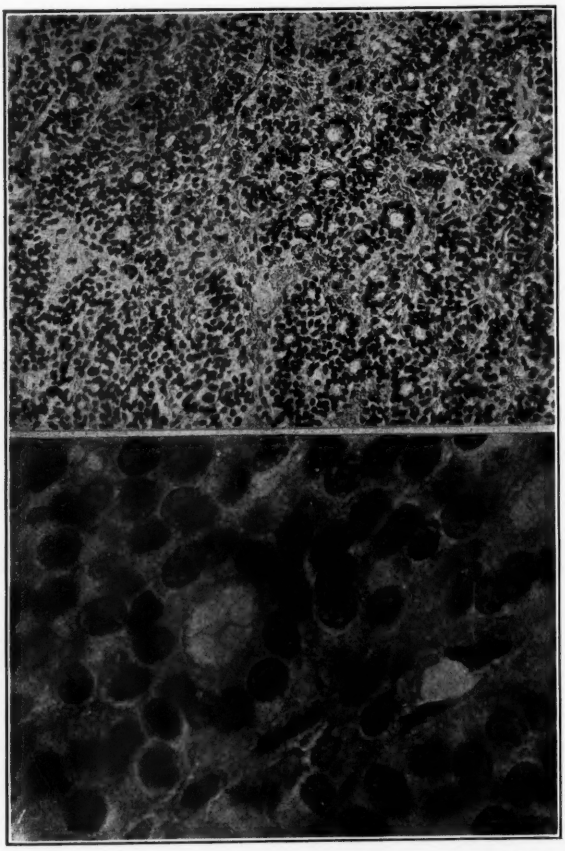

Fig. 7.—Photomicrographs, at different magnifications, of neuroepithelioma of the lung, showing arrangement of cells to form true rosettes. Under high power cilia-like projections are seen springing from the membrane about the lumen. (Hematoxylin-eosin and phosphotungstic acid hematoxylin.)

formed, and the sixth rib retracted upward. The pleura was adherent. Approach was carried forward, working from the mediastinum outward, with incision of the endothoracic fascia and the separation of the fissure between the upper and the middle lobes. Further exploration revealed a tumor mass in the apex of the right lower lobe about the size of a hen's egg. This tumor lay within the substance of the lung at a depth of about 1 cm. It was of firm consistency and seemed to be definitely encapsulated. The tumor was separated from the surrounding tissue by

blunt dissection, which caused some rather brisk venous bleeding. The operation was therefore interrupted at this point after the tumor had been about two-thirds freed and the surrounding tissues were packed with gauze and the skin was closed loosely over the pack.

Nine days later the wound was reopened and the further dissection of the tumor completed. In this process a small part of the tumor was found adherent to the bronchus, and this bit was also removed. The wound was then packed and left open. Firm dressing was applied. The wound closed gradually by granulation, and after a period of two weeks the patient was able to be up and about, although the wound continued to drain. She was discharged on October 30, with a bronchial fistula still present.

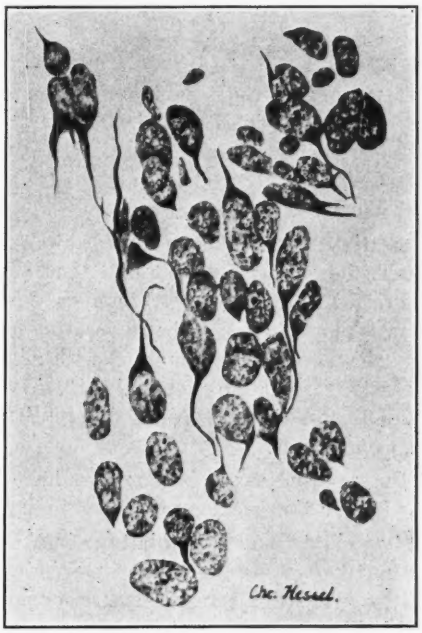

Fig. 8.—Neuroepithelioma of the lung. Artist's drawing from the silver preparation showing cell processes.

Microscopic Examination.—The tumor is composed of masses of cells with a relatively small amount of stroma. The tumor cells have little cytoplasm, and their nuclei which are round or elliptical are rich in chromatin. No mitoses are to be seen. A most striking characteristic is the tendency of the tumor cells to surround small spaces, the lumina of which are entirely empty except for some coagulum (Fig. 7). The cells about these are more cylindrical with basal nuclei, and on their inner ends have cilialike projections. In silver preparations a number of the cells are seen to bear taillike processes which stain intensely black (Fig. 8).

Pathologic Diagnosis.—Neuroepithelioma of the lung.

At an earlier point in this paper I have included the ganglioneuromas among the benign tumors of neurogenic origin; and, when they

contain ganglion cells of the adult type, this is certainly relatively correct. As previously stated, however, the sympathetic ganglion cells develop from the neuroblasts and these in turn from the sympathicoblasts; and, while it is possible to set up differential criteria for the recognition of these cell types, the separation of the tumors into ganglioneuromas, neuroblastomas, and sympathicoblastomas, as Bielschowsky points out, is necessitated more by didactic requirements than by actual conditions. In reality tumors of the sympathetic almost always contain cells of varying stages of development with those relatively less mature, or relatively more mature, predominating. It can, however, be very definitely said that the degree of malignancy corresponds with the preponderance of the immature elements. This is particularly true as regards the tendency to metastasize.

The malignant tumors of the sympathetic primordia include the more primitive sympathigoniomas and the relatively better differentiated neuroblastomas. The terminology in the literature is somewhat confused, but after all the only real distinctions to be drawn concern relative immaturity of the component cells.

The least differentiated are made up of an alveolar arrangement of cells which resemble lymphocytes except that they contain more cytoplasm and have a tendency to be arranged in rings, the so-called pseudorosettes. In other tumors there may be some differentiation, the cells having processes which can be impregnated with silver. Others may show cells approaching ganglion cells in that they are bipolar or unipolar, and, finally, all these types of differentiation may be encountered in the same tumor.

In almost all the reported cases these tumors have been found outside the thorax—by far the greater number primary in the adrenal.

We have had two chest tumors of this type in the New York Hospital during the past two years, the cells of which justify their classification as primitive sympathetic tumors: one composed of relatively more mature cells, the other with such primitive cells preponderating as to warrant its designation as a sympathicoblastoma or sympathigonioma.

One of these occurred in a white boy nine years of age, who was admitted to the New York Hospital because of pain in the back and weakness of the legs. Family history and past history were irrelevant to the present complaint. Four months before admission the child began to complain of pains in the thoracic region of the spine. These pains became more and more severe during the month before admission and were described as aching, rather than sharp, occurring both day and night and frequently causing him to cry. He attended school, however, played as usual and seemed otherwise in good health until four days before admission when he woke up at night crying with pain; his left leg was paralyzed and the right leg was found to be weak. There was considerable pain in both lower extremities, generalized. On the following day he was seen by the family physician who referred him to the hospital.

Physical Examination.—Temperature 37.8° C.; pulse 92; respiration 20.

Well-developed, well-nourished Jewish male of nine, restless, complaining of pain in the back, referred to the midthoracic region; generally hyperesthetic, more so in lower extremities and back.

Chest: Well-formed thorax, symmetrical. Abdominal breathing. Lungs clear to percussion and auscultation except in left interscapular region where the percussion note is dull from the spine to the tip of the scapula and extending from the fourth to seventh vertebrae. Breath sounds are suppressed under this region. No râles heard.

Extremities: Normally developed and symmetrical. No atrophy. Unable to move the left leg, but exhibits a withdrawal reflex on painful stimulation. Right leg seems generally weak. Joints normal.

Mental Status: Sensorium clear; precocious mentality.

Neurological: Muscular—complains of pain on pressure practically everywhere, but especially the abdomen, back, and lower extremities. The left leg shows a complete flaccid paralysis. Can flex right leg but has little power. Cannot sit up because of severe pain in his back.

Reflexes: Cranial nerves normal. Deep tendons hyperactive and equal (exaggerated especially in lower extremities). There is bilateral ankle clonus, well sustained. Abdominal present and hyperactive in lower quadrants; absent in upper. Cremasteric equal and active. Kernig suggestive on left, positive on right. Brudzinski negative on left, ? positive on right. Strength grip is normal. Vibration sense slightly impaired on left ankle.

Laboratory Data.—

Schick negative; Mantoux negative to 0.1 mg.

DATE	HG	R.B.C.	W.B.C.	AP	IP	L.	M.	E.
4/18/35	110%	5.50M	9,100	50	8	40	1	1
4/22/35	100%	5.4	12,650	72	13	15		
4/24/35	94	5.02	14,200	70	10	20		

Urine: Negative. Culture (4.27) negative.

Postmortem: Blood and cerebrospinal fluid culture negative.

X-ray Examinations.—April 19, 1935. Spine: No definite variation from the normal in bony structures. The vertebral bodies show no erosion or change in architecture; the joint spaces are negative. In the anteroposterior view there is a circumscribed semicircular shadow extending from the sixth to the ninth dorsal segments on the left side which is visible through the heart shadow in this area. The shadow appears well circumscribed and of marked increased density. In the lateral view the same shadow is visible and overlaps the spine in this portion extending well anterior to the vertebral bodies. The shadow does not appear fusiform in shape, but almost sacculated. There is no evidence of bone involvement in this area, and the findings probably represent a newgrowth of neurogenic origin rather than abscess formation (Fig. 9).

April 22. Spine: The lumbar and dorsal spine shows a dense tumor mass extending chiefly to the left of the bodies of the sixth and the ninth thoracic vertebrae. There is a slight extension of the tumor mass on the right also. Tumor mass is well defined and is made up of several layers. There is a very slight scoliosis to the right in this region, and there is some erosion of the left pedicle of the eighth segment. Otherwise there is no variation. The intervertebral discs appear quite clear. Findings suggest a soft tissue tumor probably neurogenic in origin.

Course in Hospital.—By the fourth day the neurologic status became clear. Abdominal and cremasteric reflexes were absent. There was total sphincter continence. The knee and ankle jerks were absent. There was no longer any ankle clonus and

there was a bilateral positive Babinski. A definite sensory level to pin prick could be outlined at about the fifth and sixth dorsal roots. The marked hyperesthesia had disappeared. There was complete paraplegia. X-ray pictures showed a mass from the sixth to the ninth dorsal segments on the left (Fig. 9). X-ray interpretation based on the presence of erosion of the left pedicle of the eighth segment suggested a cord tumor in this region. The child's temperature rose to 40° on the fourth day and no cause could be found. Despite this elevation a laminectomy and partial resection of the cord tumor were performed on the following day by Dr. Heuer—partial because collapse of the patient made immediate withdrawal necessary. The tumor was found to lie between the sixth and the ninth dorsal segments and to constrict the cord at the level of the eighth.

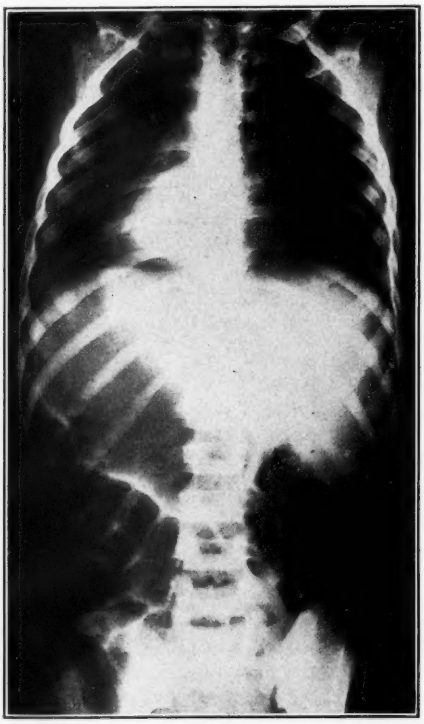

Fig. 9.—X-ray of sympathicoblastoma (sympathigonioma) springing from the seventh thoracic nerve root which grew both into the posterior mediastinum and into the spinal canal, producing cord compression and paraplegia.

Patient was returned to the ward in shock and revived at length with parenteral fluids and transfusion. The temperature remained elevated between 39° and 41° for the next five days, and postoperative course was progressively downhill. Despite transfusion and other supportive measures, the patient died April 28.

AUTOPSY RECORD

Pleural Cavities.—The left pleural cavity contained approximately 200 c.c. of frankly bloody fluid. Situated in the left posterior mediastinum adjacent to and just lateral to the seventh and eighth thoracic vertebrae there was a tumor mass which

measured 4 cm. in diameter and was of a grayish white hemorrhagic color. The parietal pleura over this mass was eroded and hemorrhagic. The visceral pleura overlying the tumor mass was also hemorrhagic, and there was a thin tumor mass measuring 1 cm. across which infiltrated the visceral pleura. The pleural surfaces over both apices were smooth, glistening, and free from adhesion.

Lungs.—Together the lungs weighed 340 gm. They were of the usual size, shape and crepitance for a child of this age. There was a slight enlargement of the tracheobronchial lymph nodes which measured from 0.5 to 1 cm. in diameter. On section these nodes were grayish white in color and soft in consistency. The cut surfaces of both the lungs presented the usual architecture, and there was the usual crepitance throughout all lobes. As described above there was a small growth of tumor tissue measuring 1 mm. in thickness and 1 cm. across, situated in the visceral pleura of the posterior part of the left lower lobe. The underlying lung tissue for a matter of 0.5-1 cm. was congested and hemorrhagic. Except for this small area the lung tissue was not remarkable.

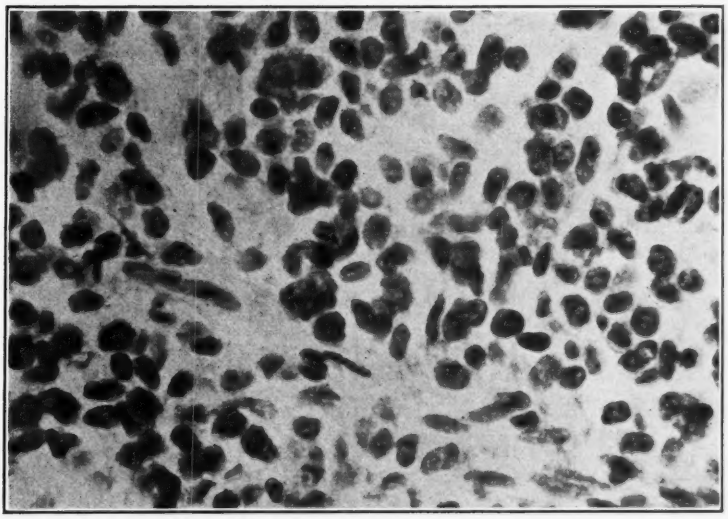

Fig. 10.—Photomicrograph of tumor from the patient in Fig. 9. The tumor is a sympathicoblastoma (sympathigonioma) composed of primitive cells, the precursors of both the sympathetic nerves and the chromaffin tissue. A pseudorosette is seen in the center of the picture. (Hematoxylin-eosin.)

Spinal Cord.—Situated within the spinal canal there was a tumor mass arising at the site of the seventh spinal ganglion on the left, and encircling one-third of the spinal cord. This tumor measured 5 cm. in length by 1 cm. in breadth by 0.5 cm. in thickness. This tumor was crescent shaped and entirely separate from the spinal cord, and extended outward through the foramen of the spinal canal forming a much larger tumor mass just lateral to the vertebral column which measured 6 × 4.5 × 3.5 cm. The tumor mass was gray white in color and firm in consistency. On section it presented a gray white and hemorrhagic surface. The roots of the spinal nerve could be identified as they left the cord and almost immediately entered the tumor mass within the spinal canal. Also the spinal ganglions below and above the tumor were easily identified.

Microscopic Examination.—Tumor: A section taken from the tumor mass situated in the left posterior mediastinum showed an extremely vascular tumor

with much hemorrhage and necrosis. The tumor consisted of small round cells with poorly defined nuclei which, for the most part, were only slightly vesicular. Mitotic figures were seen in moderate numbers. The tumor cells were growing in a medullary manner for the most part, but in some areas the cells were accompanied by a moderate amount of loose fibrillar type of stroma which took a faint pinkish stain.

A section of the tumor stained with Masson's trichrome and Cajal for neurofibrils showed the tumor to consist of masses of cells with rounded nuclei and scanty cytoplasm not unlike lymphocytes in many places. These cells lay in spaces between well-defined strands of collagen. They had no processes as far as they were examined, nor was there any evidence of well-defined neuroblast formation. There was little, if any, evidence of rosette formation. This microscopic appearance, together with the situation of the tumor, makes it probable that we are dealing with the most primitive type of tumor derived from the sympathetic system, i.e., the sympathicoblastoma or sympathigonioma (Fig. 10).

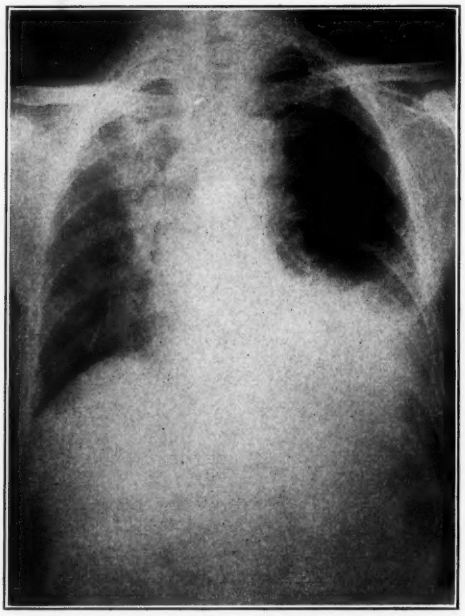

Fig. 11.—X-ray picture of case of neuroblastoma of the mediastinum which invaded the lung, pleura and pericardium.

Diagnosis.—Sympathigonioma of seventh spinal nerve root with pressure on spinal cord and extension into posterior mediastinum.

Myelomalacia of spinal cord at, above, and below level of tumor.

This, then, was an example of the most primitive type of tumor of the sympathetic nervous system. It was highly invasive and probably because of its site of origin the primary tumor assumed an hourglass shape.

The second case was that of a fifty-five-year-old Jewish male, who was first admitted to the New York Hospital Dec. 14, 1933, because of fatigue, dyspnea and

pain in the right shoulder of eighteen months' duration. These symptoms had become markedly accentuated following a respiratory infection eight weeks previously. He had lost about 9 pounds in weight. In the hospital he was found to have marked evidence of mediastinal pressure with dilatation of the veins of the neck. The x-ray examination showed a paralysis of the right half of the diaphragm, and a mass in the posterior mediastinum above the heart (Fig. 11). The spleen was palpable.

The tumor was believed to be inoperable, and the patient was given a series of x-ray treatments with some improvement for about a year. His symptoms then progressed and he was readmitted to the hospital Nov. 29, 1935, cyanotic and dyspneic and with x-ray evidence of increase in the size of the mass and fluid in the left pleural cavity.

A summary of his physical examination and course in the hospital follows.

Physical Examination.—Temperature 37.2°; pulse 90; respiration 30; blood pressure 172/118; patient undernourished, orthopneic, dyspneic, cyanotic, acutely ill, coughing thick greenish sputum. Old traumatic scar in right cornea. Teeth carious. Veins of the neck distended. Moderate dilatation of superficial veins of chest and abdomen. Increase in supracardiac dullness to right and left; flatness left lung base with absent breath sounds and vocal fremitus. Râles and tubular breathing anteriorly over right intraclavicular region. Dullness, diminished breath sounds right base. Spleen palpable.

Laboratory Studies.—Urine: sp. gr. 1.030; albumin four plus; 3-5 R.B.C.; 3 W.B.C.; 30 casts granular and hyalin/high power field.

Blood: R.B.C. 4.8 mil; Hg 95 per cent, W.B.C. 10,600; adult polymorphonuclears 56; immature polymorphonuclears 26; serology negative; urea N. 28 and rising to 35 third day after admission. Total protein 5.7; serum albumin 3.4; serum globulin 2.0, Dec. 2, 1935.

Urea Clearance Test: Standard, first specimen 50 per cent; standard, second specimen 36 per cent.

No acid-fast organisms found in sputum on two examinations.

Course and Treatment.—Nine hundred c.c. of grossly bloody fluid were removed from the left chest the day after admission; sp. gr. 1.016; albumin four plus; sediment consisting of erythrocytes, lymphocytes, occasional neutrophiles and plasma cells and large round cells thought to represent swollen endothelial cells. Cultures were sterile. After removal of fluid, many coarse metallic-like râles were heard over anterior lower left chest and axilla extending almost to clavicular region. With patient prone, a coarse, metallic sound was heard over entire precordium synchronous with heart sounds, but obscuring them and being loudest on expiration. This disappeared with the patient in upright position. Rectal temperature remained between 37° and 38°; the pulse 90-110; respiration 20-30. Treatment consisted of sedatives and symptomatic measures. Patient showed no improvement and quietly died the eighth day after admission.

AUTOPSY FINDINGS

Pleural Cavities.—The left pleural cavity contained 850 c.c. of serosanguineous fluid which was slightly cloudy. The right pleural cavity contained 250 c.c. of cloudy yellowish fluid. The right parietal pleura was bound to the right visceral pleura by innumerable adhesions between the left parietal and the visceral pleurae. Both lungs were firmly adherent along their median borders. There was a large gray nodular mass firmly adherent to the left parietal pleura. This mass lay inferior to the eighth intercostal space. It measured 15.5 cm. in length, 7 cm. in width in its widest portion, and approximately 3 to 4 cm. in thickness. It was a dull grayish

blue color, soft in consistency. It was not adherent to the visceral pleura. When removed it weighed 105 gm. On section it had a moderately fibrous stroma arranged in parallel bands. Interspersed with the tumor tissue were hemorrhagic areas.

Lungs.—The lungs together weighed approximately 850 gm. The visceral pleura of the right lung was tightly adherent to the parietal pleura by numerous fibrous adhesions. These also bound the inferior surface of the lower lobe to the right diaphragm. The median surface of the lung was tightly adherent to a white fibrous mass in the mediastinum. The median and superior portions of the right lung were tightly adherent to the parietal pleura and when the lung was removed the visceral pleura adhered to the parietal pleura. No masses were found in the lung parenchyma other than at the hilum of the lungs where a number of large black lymph nodes were felt firmly imbedded at the hilum. The median edge of the left lung was tightly adherent to the mediastinal structures and to the internal surface of the left thoracic cage. Beneath the pleura of the left lung there were a number of dull gray nodular masses scattered indiscriminately throughout both lobes. Particularly on the inferior surface of the lower lobe of the left lung there was a very large mass of gray

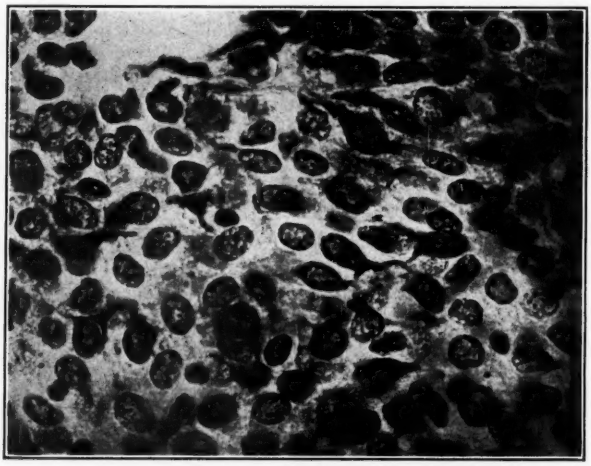

Fig. 12.—Photomicrograph of tumor from patient whose x-ray is shown in Fig. 11. Four stages in the differentiation are to be seen, represented by the small cells with dark staining nuclei, those with larger vesicular nuclei, and, finally, the bipolar and unipolar cells whose processes stain black.

nodular material. On section both lungs showed a dark purplish red color. The alveolar structure could not be made out distinctly, and there was very little crepitation present in any part of the lungs. The trachea and major bronchi showed a mucosal surface which was bright red in color and edematous. A portion of the bronchial tree directly beyond the major division of the bronchi seemed a little larger than normal although not strikingly so.

Mediastinum.—The anterior mediastinum situated superiorly to the pericardium showed a large white fibrous mass which measured 1.5 cm. in thickness, 4 to 5 cm. in width and 8 cm. in length. This white mass infiltrated all surrounding structures including the anterior mediastinal lymph nodes. It also went down onto the base of the pericardium.

Heart.—The parietal pericardium was extensively infiltrated with the whitish mass described above. The material extended through the parietal pericardium onto the visceral pericardium, surrounding the bases of the great vessels and going on to the

epicardium. Beneath the epicardium particularly on the left ventricle there were a number of small white nodules which were discrete and round. The largest of these measured 12 mm. in diameter.

Microscopic Examination.—A section of the tumor stained with silver showed it to be composed of primitive nerve cells of varying degrees of differentiation. The most primitive are seen as small cells with relatively little cytoplasm and with nuclei which stain intensely black. Most numerous are somewhat larger cells, with vesicular nuclei, which may be considered as sympathicoblasts, and scattered throughout the sections are others resembling primitive unipolar and bipolar ganglion cells (Fig. 12).

Pathologic Diagnosis.—Neuroblastoma.

This patient then had a tumor which ran a more chronic course than that of the previous patient and which on microscopic examination showed much greater differentiation of the cells, although it too was quite malignant.

The elements of the somatic nerves have been excluded from the bracket in the table of histogenesis only for the sake of simplicity, but it is obvious that from them may arise any of the tumors of the peripheral nerves which have been mentioned. Nor have I spoken of a pure tumor of neurones, the true neuroma. These tumors, which are extremely rare in any location, are made up of masses of axis cylinders with their sheaths. I know of no reported chest tumors which exactly fulfill these criteria, but it may be that they will be reported in the future.

Finally, I have excluded the so-called paragangliomas, or tumors of the chromaffin tissues—the descendants, like the sympathetic ganglion cells, of the primitive sympathigonia—largely because this tissue does not occur normally in the chest. However, Lewis and Geschickter[9] mention a paraganglioma of the chest wall involving the upper part of the sternum which invaded the lung, and, considering the histogenesis of its parent tissue, we can postulate that such a neoplasm might occur within the chest either as a pure chromaffin tumor or as part of one of the more complicated tumors of the sympathetic primordia.

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EXPERIMENTAL PRODUCTION OF BRONCHIECTASIS*

Study Based Upon Pulmonary Changes Occurring With Bronchial Obstruction

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KNOWLEDGE of the pathogenesis and pathology of bronchiectasis has been attained almost entirely through clinical observations. Since this has left a number of points in dispute, it would seem desirable to investigate the subject experimentally. Foreign body occlusion, a recognized cause of severe bronchiectasis, serves as an admirable approach for the latter method of study, not only for a further understanding of the principles underlying the development of infection and ectasia, but for the clarification of apparently conflicting views regarding the severity of suppuration due to foreign body obstruction as compared to other forms of pulmonary suppuration. Hedblom[1] described this type of disease as the most severe form seen clinically, and Graham, Singer and Ballon[2] state that "if a foreign body has been allowed to remain in the lung until irreparable damage has been done, then the outcome, even after withdrawal of the foreign body, may be most unfavorable." These observations are in striking contrast to the assertion of Chevalier Jackson[3] that "pulmonary suppuration starting endobronchially and due to the presence of a foreign body is, when contrasted with embolic, post-pneumonic and post-influenzal suppuration, such a mild, slow and restricted process, and manifests such a tendency to prompt and complete recovery after removal of the foreign body as to suggest the existence of some sort of physiological or structural barrier against the invasion of suppurative processes by the endobronchial route."

Previous experimental work which has been concerned with bronchial occlusion may be divided into two groups. In the first group the occluding body has served the purpose of carrying specific organisms into the lung and acting as a barrier to their escape. In those instances in which lung suppuration has been induced, no mention is made of bronchial enlargement, although in the light of results reported here, dilatation must have occurred. In the second group, represented chiefly by the work of Lichtheim[4] and Coryllos and Birnbaum,[5] bronchial occlusion has been established mainly for the purpose of studying phenomena other than bronchial dilatation, although this change has been referred to.

*Read (by title) at the Nineteenth Annual Meeting of the American Association for Thoracic Surgery at Rochester, Minnesota, May 4, 5, 6, 1936.

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EXPERIMENTS

In performing experiments with foreign body occlusion of a bronchus it was desired that the procedures simulate closely the conditions obtaining in actual human experience. It was found, after a trial of several methods, that obstruction could be most satisfactorily induced in the rabbit lung by introducing a sandbur into the bronchus through a transtracheal incision. This route was chosen to facilitate the insertion of the bur and to avoid contamination of the bur by mouth organisms. The barbed seed was used because it tends to remain fixed in the bronchus through the action of the barbs for a sufficient length of time to establish pathologic changes. The instrument used to introduce the bur into the bronchus consisted of a flanged ureteral catheter fitted with a stylet of piano wire. The stylet served the dual function of giving rigidity to the catheter during its passage through the tracheobronchial tree, and acting as a means of dislodging the bur from the flanged end of the catheter when resistance to further passage was encountered. At the time of operation no attempt was made to determine in which bronchus the foreign body was lodged. Aseptic technic was used throughout, including previous sterilization of the foreign body, in order to minimize the introduction of outside organisms. All experiments were performed under ether anesthesia.

The lungs were examined at various intervals after introduction of foreign bodies, and by this means the progress of the changes occurring in the lungs was noted. Foreign bodies were successfully lodged in the tracheobronchial tree in 22 instances. As the results at corresponding intervals were uniform with few exceptions, only representative findings and the exceptions are reported in detail.

Group 1.—Three animals were examined postmortem within twenty minutes after introduction of the bur into the bronchus. In these animals the lobe or lobes distal to the bronchial obstruction were much larger than the other lobes of the lung. Histologic specimens revealed a striking enlargement of the alveolar spaces and congestion in the affected lobes. Numerous breaks were seen in the alveolar walls, but it could not be determined whether or not these were artefacts. Apparently at this stage the obstructing body acted as a valve which permitted ingress but not egress of air, in the manner described by Jackson.

Group 2.—The animals died or were killed from six hours to forty-eight hours after lodgment of the foreign body. The findings in an animal which was killed forty-eight hours after operation are described in detail as they are typical of the changes occurring in this group. The foreign body was found lodged firmly in the main left lower lobe bronchus. It already showed a loosely attached mucopurulent membrane. The obstructed lobe showed patchy areas of congestion. Other lobes were normal grossly. Histologic examination showed definite peribronchial atelectasis and congestion with some evidence of leucocytic infiltration and occasional smaller areas of atelectasis in the parenchyma

away from the larger bronchi. In some fields there was excessive rupture of the alveolar walls. The fact that this tearing was much more pronounced than in the unobstructed lobes suggests that it was not artificial, and that it may have been the result of hyperinflation at an early stage.

The principal alterations of recent partial bronchial obstruction would appear to be localized bronchial and peribronchial inflammation, with patchy atelectasis in the latter areas.

Group 3.—This group consists of the animals with evidence of complete bronchial obstruction and marked bronchiectasis in which the lungs were examined from fourteen to fifty-eight days after lodgment of the foreign body in the tracheobronchial tree. Of 10 animals show-

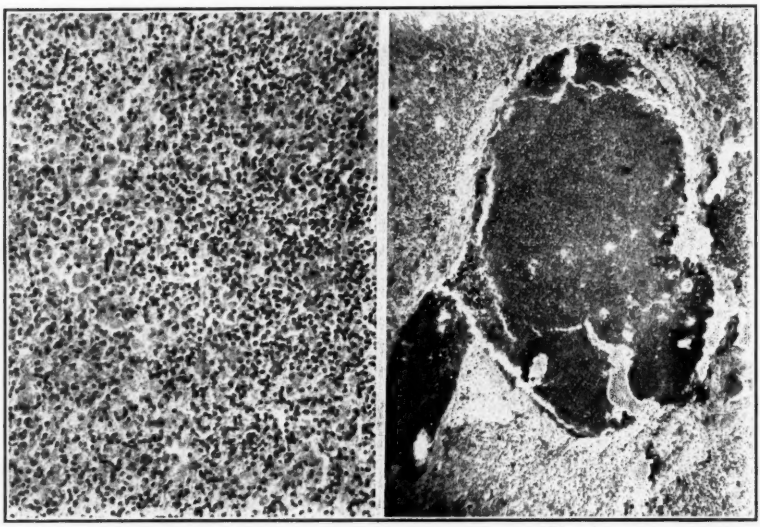

Fig. 1. Fig. 2.

Fig. 1.—R6A. Atelectasis in an obstructed lobe fourteen days after lodgment of barbed seed in a bronchus (×130).

Fig. 2.—Same section as Fig. 1 in lower magnification. Note dilated bronchus filled with purulent exudate (×42).

ing complete bronchial obstruction, 8 died within twenty days, one on the fifty-sixth day and one on the fifty-eighth day. The changes seen at the end of fourteen, twenty and fifty-eight days are described in detail as illustrative of the progression of pathologic changes in this group.

R6. Death occurred fourteen days after the bur was inserted into the tracheobronchial tree. Postmortem examination showed the bur lodged in the right main bronchus. The foreign body was decomposed and was covered with a thick fibrinopurulent membrane. The right lung was smaller and of more solid consistency than normal and was dark red. The left (nonobstructed) lung was of normal size, moderately congested, and loosely adherent to the parietal pleura.

Histologic examination of sections from the right lower (obstructed) lobe showed complete collapse of the alveoli except for very small clusters at the extreme

periphery of the lobe (Fig. 1). The parenchyma was congested, with moderate leucocytic infiltration. Occasional areas showing dense leucocytic infiltration were interpreted as incipient abscesses. The bronchi and bronchioles were distended with pus and for the most part showed a smooth cylindrical contour, only a few of the bronchioles retaining their normal rugous lining (Fig. 2). The walls of the bronchi, including the cartilage plates, showed degeneration and necrosis. The bronchial lumina were definitely enlarged, and the smooth cylindrical outline of the bronchioles together with the loss of the normal rugae of the mucosa indicated their enlargement also. The section represented a lung in an early stage of massive bronchiectasis and atelectasis.

Histologic examination of the left lower (nonobstructed) lobe revealed a generalized acute inflammatory reaction with congestion. There were occasional areas of bronchopneumonia around bronchioles containing purulent exudate. In some of these bronchioles the rugae were absent, indicating dilatation.

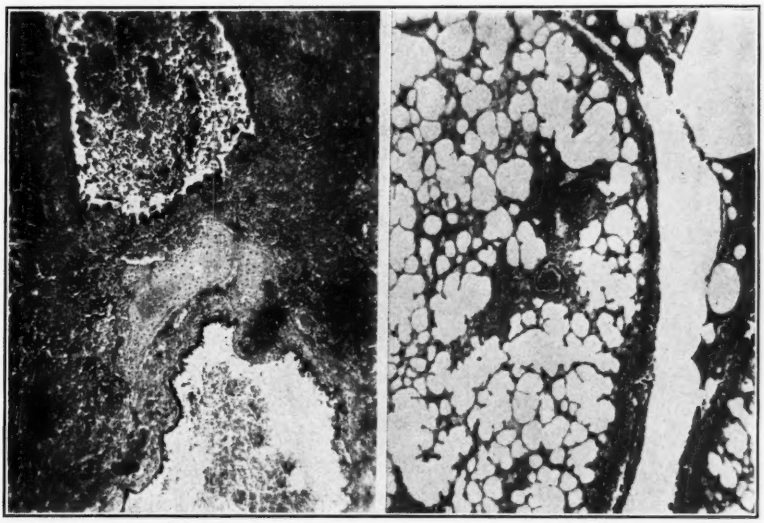

Fig. 3. Fig. 4.

Fig. 3.—R10A. Bronchiectatic cavities and atelectasis with infection in an obstructed lobe twenty days after lodgment of foreign body. All coats of the bronchial walls are involved in the degenerative and necrotic changes (×42).

Fig. 4.—Secondary bronchiectasis in nonobstructed lobe of twenty-day animal due to spread of pus from obstructed lobe (Fig. 3). Bronchus in longitudinal section is moderately dilated and contains purulent exudate. Near the center of the section is seen a plugged bronchiole with surrounding patchy atelectasis (×42).

R10. This animal died twenty days after introduction of the foreign body. On examination of the lungs, purulent material exuded from the right main bronchus, and an encapsulated decomposed fragment of bur was found in the right lower lobe bronchus. The right lower lobe was consolidated, congested, and of smaller size than normal. On cut section, the bronchi were conspicuous, and exuded pus. The left lower (nonobstructed) lobe showed purulent exudate in the bronchi on cut section, but not to the degree seen in the bronchi of the obstructed right lower lobe.

The histologic changes in the obstructed lobe were comparable to those seen in the fourteen-day animal (Fig. 3). The pathologic changes in the nonobstructed left lower lobe were moderately advanced as evidenced by profuse purulent exudate, and extensive patchy atelectasis with inflammatory changes (Fig. 4).

In these animals there was massive atelectasis in the obstructed lobes, and definite bronchial degeneration and ectasia. The nonobstructed lobes showed an early bronchiolitis, and peribronchial atelectasis and pneumonitis. The changes in the nonobstructed lobes are interpreted as being the result of spreading of pus from the diseased obstructed lobe into the bronchial tree of the nonobstructed lobes.

Of special interest are the smooth contour vacuoles in the parenchyma of the obstructed atelectatic lobes. These were seen in all obstructed lobes, and had much the appearance of artefacts.

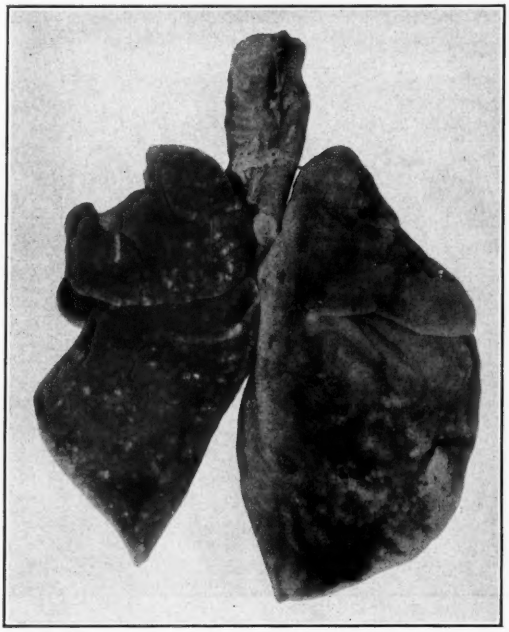

Fig. 5.—R8. Posterior view of lungs of rabbit fifty-eight days after lodgment of foreign body in left main bronchus. Left lung decreased in size due to atelectasis. Note small abscesses showing through pleura of congested lung.

R8. Death occurred fifty-eight days after the foreign body was inserted. The left lung, about two-thirds normal size, was loosely adherent to the thoracic wall, congested and dense. Multiple small abscesses showed through the pleura (Fig. 5). Cut section of the lung revealed bronchial dilatations containing purulent exudate. The decomposed foreign body was found loosely lodged in the left main bronchus. The entire tracheobronchial tree contained a fibrinopurulent exudate. The right lung showed patchy areas of congestion and purulent exudate in the bronchi.

Histologic examination showed complete atelectasis of the obstructed left lower lobe except at the extreme periphery where the change was moderate. The alveolar tissue was congested and infiltrated with leucocytes. The walls of the larger bronchi showed complete to partial patchy necrosis. The larger bronchi were greatly dilated, and all the bronchi and most of the bronchioles showed a cylindrical smooth contour

with loss of rugae. Some of the bronchioles were collapsed. Several small parenchymal abscesses were seen in the formative stage, not walled off (Fig. 6).

Histologic examination of the nonobstructed right lower lobe showed large patches of atelectasis. Much of the alveolar tissue, however, was aerated. All the larger bronchi and many of the smaller bronchi and bronchioles contained pus, and the walls were cylindrical. Other bronchioles were collapsed or of normal contour. The alveoli in the region of the pus filled bronchi and bronchioles were collapsed or filled with purulent exudate (Fig. 7).

In this group of experiments there are seen two types of bronchiectasis: the massive type associated with complete bronchial obstruction, and the more moderate type seen in the nonobstructed lobes. In the massive type, associated with the bronchial obstruction, the foreign body has caused an atelectasis, and there has been a resulting infection

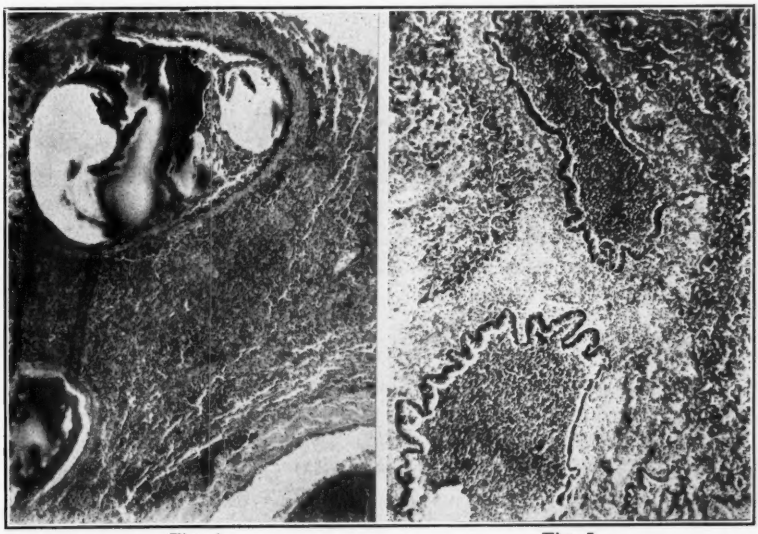

Fig. 6. Fig. 7.

Fig. 6.—R8A. Section from obstructed lobe of rabbit fifty-eight days after insertion of foreign body. Severe bronchiectasis with extensive degeneration and necrosis of all coats, and loss of rugous lining (×42).

Fig. 7.—Bronchiectasis in nonobstructed lobe of fifty-eight-day animal, due to spread of pus from obstructed lobe (Fig. 6). Note incomplete atelectasis, and retention of rugous lining in dilated bronchus. A comparison with Fig. 4 indicates the progress of the disease in the nonobstructed lobes (×42).

in the alveolar tissue and in the bronchial tree distal to the obstruction. The weakening of the bronchial tree by infection and possibly by the lytic action of the retained secretions and the change in pressure induced by the atelectasis have resulted in ectasia of the bronchial tree. At the same time the accumulation of secretion and infecting organisms has caused further degeneration and necrosis of the bronchial and alveolar tissue. In the nonobstructed lobes there was seen a patchy chronic inflammatory bronchitis and bronchiolitis together with areas of inflamed parenchymatous tissue, some of which were definitely atelectatic.

This change may be explained by the constant passage of pus into the bronchial tree from the diseased obstructed bronchi. A comparison of the photographs of the twenty-day and fifty-eight-day animals shows the progressive character of the disease on the nonobstructed side (Figs. 4 and 7).

COMMENT

These experiments would appear to indicate that atelectasis and the retention of infectious secretions are important factors in the production of bronchiectasis resulting from bronchial occlusion. Since aseptic technic was used in introducing the foreign bodies, it may be assumed that the organisms concerned with the massive suppurative infection were those normally present in the lung. The investigations of Jones,[7] Durck,[8] Boni,[9] Neisser,[10] Zuensel,[11] Spray,[12] and Livingstone and Adams[13] afford ample evidence that the lung normally harbors microorganisms which are potentially pathogenic. Furthermore, Lichtheim, as early as 1879, demonstrated experimentally that simple occlusion of a bronchus without the intentional introduction of organisms was sufficient to induce severe pulmonary suppuration, and his observation has been confirmed since in numerous clinical and experimental investigations (Coryllos and Birnbaum, Churchill and Holmes,[14] Reinberg,[15] Band[16]). This point is stressed because in almost all attempts to induce pulmonary suppuration by aspiratory methods, emphasis has been placed on the introduction of specific pathogens (Allen,[17] Crowe and Scharff,[18] Joannides,[19] Kline,[20] Schlueter and Weidlein,[21] Cutler,[22] Longacre and Hermann,[23] Smith[24] and others). Under normal conditions the presence of these organisms is no more harmful than potentially pathogenic organisms on other healthy body surfaces. The healthy bronchial tree, through the action of ciliary motion, cough, and mucous secretions is capable of inhibiting bacterial growth sufficiently to prevent or minimize infection. It may be assumed that with stoppage of a bronchus these protective agents no longer function, and the bacteria multiply and possibly become heightened in virulence in the retained stagnant secretion which acts as an ideal culture medium. In addition to this there is to be considered the possible lytic and otherwise destructive action of the secretions acting directly on the bronchial and alveolar tissues. While the possibility that aspiration of virulent organisms may cause pulmonary suppuration is not to be ignored, these experiments indicate that it is secondary in importance to bronchial occlusion.

There is also to be considered the lowering of the resistance of the lobe following bronchial occlusion. This brings in for discussion the rôle of atelectasis. It has been shown by Moore,[25] Coryllos and Birnbaum,[26] and Adams and Dostal[27] that there is a definite reduction in flow of blood through the atelectatic lung and an apparent passive congestion in the lung capillaries. This change alone would be sufficient to account for a lowering of resistance in the involved lobe. The effect

may be compared to that seen in varicose veins of the leg with their marked tendency to initiate and prolong infection. Whatever the reason is, it must be accepted from experimental and clinical evidence that severe suppurative infection of the parenchyma occurs with prolonged massive atelectasis. These experiments give additional evidence of this association. The association of atelectasis with pulmonary suppuration has been referred to repeatedly by Hedblom, Churchill, Cutler, Coryllos and Birnbaum, Jackson, and Scott.[28] The greater rôle of atelectasis, however, is in its effects on the bronchi after degenerative changes occur in the latter. Before the bronchi become weakened, they are able to withstand the change in pressure induced by the atelectasis and do not expand to fill the increased pleural space which results from the atelectasis. But after they become weakened through infection and degeneration, they are unable to withstand the pressure change, and they dilate to fill the space created by the massive collapse of the alveoli. This tendency is a physiologic response and is in itself not harmful. The resulting dilatations, however, act as reservoirs for the accumulation of pus which in turn increases the degeneration and necrosis in the lung tissue, thus establishing a vicious circle.

A finding to which I wish to call attention is the occurrence of vacuoles in the parenchyma of the atelectatic lung. Coryllos[29] called attention to these in discussing Adam's presentation on "Vascular Changes in Experimental Atelectasis" at the meeting of the American Association for Thoracic Surgery in 1934, and offered the explanation that they might represent emphysematous alveoli connected with stenosed but not completely obstructed bronchi. He admitted that such a conclusion was not beyond criticism. It will be recalled that in my experimental animals killed within two days after introduction of the obstructing foreign body, the alveolar walls showed numerous breaks. Assuming that these ruptures were not artefacts but were caused by the hyperinflation which precedes atelectasis, they would then not be subject to the air absorption which takes place in the intact alveoli, but would be subject to the same atmospheric changes as the bronchi, and would then tend to undergo the symmetrical rounded expansion which the bronchi tend to undergo. This explanation is supported by the recent work of Moolten[30] who ruptured the bronchial walls and parenchymal tissue in isolated lungs, and by inflation of the lungs produced rounded defects simulating the round cavities of lung abscess and bronchiectasis.

At this point I wish to discuss further the opinion of Jackson that foreign body occlusion of a bronchus is to be sharply distinguished from other pulmonary suppuration because of its mild tendencies. In a presentation in 1926 he stated that "the characteristics of foreign body obstruction are most marked in cases of metallic foreign bodies, which seem to possess germicidal powers . . . . they are least apparent in the cases of vegetal foreign bodies; but even in these the prompt

recovery in almost all cases, if the foreign body has not been long in the tracheal bronchial tree, is in marked contrast to the lung suppuration of any etiology other than foreign body." He does not explain the tendency of vegetable foreign bodies to produce more persistent suppuration, except to ask the question "do vegetal substances break down the barrier against pyogenic invasion?" It is difficult to believe that metallic foreign bodies exert a sufficient bactericidal effect definitely to inhibit bacterial growth. The very fact that all metallic foreign bodies, although of different chemical composition, show the same tendency to produce only mild and temporary suppurative lesions would in

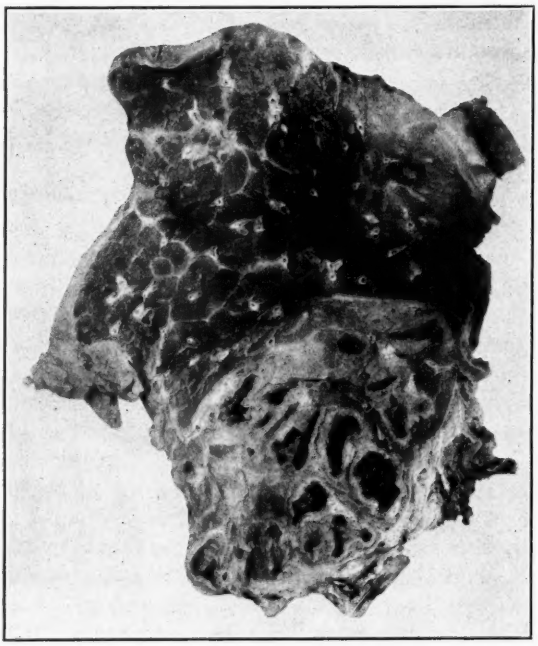

Fig. 8.—Specimen from girl, aged twenty years. Bronchiectasis of middle and lower lobes due to lodgment of tack in the middle lobe bronchus.

itself argue against germicidal properties. On the basis of the experiments which I have reported, the degree of infection is a question of completeness of obstruction rather than any directly favorable or unfavorable action which the foreign body may have on the bacteria within the lung. As Jackson himself states, the metallic foreign bodies, such as tacks, screws and pins, cannot completely occlude the bronchus because of their irregular contour. In the absence of complete plugging of the bronchus there would be neither atelectasis nor complete retention of infectious secretion, the two factors which my experiments indicate to be of chief importance in producing severe massive pulmonary sup-

puration. It is not necessary to assume immediate complete obstruction with the introduction of a foreign body. Incomplete obstruction will in most cases become complete sooner or later through the encapsulation of the foreign body by inflammatory exudate, and by swelling of the bronchial tissues around the foreign body.

If a metallic foreign body does remain in a bronchus for a long period of time, severe irreparable bronchiectasis may occur and may be as persistent and severe as any other type of bronchiectasis experienced clinically, if not more so. I have an example of what may occur with complete obstruction due to lodgment of a metallic foreign body in the case of a girl, aged twenty years, who came under my observation with all the characteristic findings of a severe saccular bronchiectasis including profuse, foul sputum, clubbing of fingers and toes, acne and undernourishment. At autopsy a tack, so corroded and decayed that it could not be lifted from the bronchus without crumbling, was found completely obstructing the right middle lobe bronchus. The accompanying photographs show the state of the involved lobe with numerous sacculations, bronchial wall destruction, fibrosis and abscess formation in the parenchymal tissue, changes which under no consideration could be considered reparable (Fig. 8). This specimen, as well as the specimens from the experiments, affords striking evidence of the progression of pulmonary suppuration with complete foreign body obstruction.

CONCLUSIONS

What would appear to be an error in previous explanations of bronchiectasis and other pulmonary infections incident to foreign body obstruction is the fact that they invoke the necessity of introduction of foreign organisms. In this work, contamination has been avoided as effectively as possible, and there is reason to believe that the suppurative changes observed here were due to organisms already present and only of latent pathogenic power. Unquestionably the fresh introduction of highly virulent organisms would accelerate these changes, but I wish to emphasize that, possibly to a lower degree, they will occur in their absence. The decisive factor would appear to be that of bronchial obstruction operating both through the induction of changes in the pulmonary tissue and by obstruction to drainage from the involved area. The secretions, which form in excess as a result of irritation by the foreign body, cannot go outward; and, as the tension from their accumulation increases, they are forced into the alveolar tissue, carrying with them the bacterial flora whose virulence would tend to be heightened by retention in the fertile medium of stagnant secretion, with the additional factor of circulating changes occasioned by the atelectasis which itself is a sequel of the obstruction.

The mechanism of bronchiectasis in these circumstances is apparently accumulative destruction with resultant weakening of the bron-

chial wall. This gradually yields to the effects of the increased difference between intrabronchial and extrabronchial pressure induced by the atelectasis; since even with complete obstruction there comes a time when the obstructing body will have disintegrated sufficiently to permit ingress of air on inspiration. No great obstruction to egress of air need be assumed, since the bronchial wall will eventually be weakened to the point where it undergoes distention even with normal inspiratory pressure.

These studies would indicate that bronchiectasis due to aspiration of purulent secretion is an entity distinct from the obstructive type in the manner of degree and rapidity of development, although the underlying principles are the same in both. In the case of the former the infecting organisms play a dominant rôle early in the establishment of the disease by the prolonged contact of purulent exudate with the bronchial tree. The bronchi, which are always resisting the difference in pressure between atmospheric air and that of the pleural space, become weakened through infection, and as a result they gradually enlarge to a degree dependent upon the degree of weakening. This at first results in a slight dilatation comparable to that seen in bronchitis. The degree of dilatation which may eventually occur will depend upon the destructive power of the bacterial flora and upon the duration of the process. At the same time there is an extension of the infection into the alveolar tissue. It is also probable that localized atelectatic areas develop as the result of plugging of the bronchi and bronchioles with inspissated exudate. With these several factors working together, there may eventually occur a disease comparable in severity with obstructive bronchiectasis; but always the former will be a slowly developing process, while the latter will be a rapidly developing one.

SUMMARY

1. A simple method of occluding the bronchus of a rabbit with a foreign body introduced transtracheally is described. This method has the advantage of introducing the foreign body without contaminating it with buccal or other outside organisms. By means of this method it has been possible to observe the progressive changes occurring in the lung with bronchial obstruction.

2. Occlusion of a primary or secondary bronchus of a rabbit with a barbed seed results in severe bronchiectasis associated with massive atelectasis and infection.

3. The experiments indicate that atelectasis is an important factor in the development of obstructive bronchiectasis.

4. The organisms concerned in the infectious processes associated with the bronchiectasis appear to be those normally found in the lung. It has not been necessary to introduce pathogenic organisms with the foreign body to produce bronchiectasis.

5. A less severe type of bronchiectasis occurs in the nonobstructed lobes as a result of the spread of purulent secretion from the originally diseased lobes. This type simulates the type of cylindrical bronchiectasis seen in man in which the process is the result of the spread of purulent material from other parts of the respiratory tract.

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CONSERVATION OF THE FIRST RIB IN APICOLYTIC THORACOPLASTY*

Procedure and Advantages

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THE operative procedures of surgery can never be completely standardized because no two cases are exactly alike; so the surgeon should have an artistic as well as a mechanical sense.

In the pathologic deformities of the thorax and its contents resulting from the changes brought about by tuberculosis of the lungs we find that the commonest and probably the most important is the formation of cavities. Major surgery is invoked to promote healing by obliterating these spaces, large or small. The other therapeutic measures designed to combat tuberculosis need not occupy us here.

Since the inception of thoracoplasty we have seen many modifications, all looking toward the local or general reduction in the capacity of the pleural sac so that pulmonary cavities may become obliterated. The most outstanding procedure is the Sauerbruch paravertebral resection of the eleven upper ribs.

In the beginning the lower ribs were the first to be resected, and this became the rule.[1] It then occurred to me that since the principal seat of tuberculous cavities was usually in the upper lobe, the ribs over this region might well be the first to be attacked. Besides, the first rib seemed to me to act as a support to those below through its muscular and fibrous connections with them.[2] On account of the immediate reduction in the size of the diseased upper lobe, it seemed reasonable from all surgical aspects to leave a number of the lower ribs intact, at any rate for the time being. Should further collapse become necessary or advisable the lower resections could be made at a later time. (Case 3.) The result in most of the cases treated by me in this sequence was that the function of the lower, healthy portion of the lung was permanently retained.

Certain large or rigid-walled upper lobe cavities could not be obliterated by merely resecting or even excising the overlying ribs, and therefore we began to combine upper thoracoplasty with gauze packing or with the permanent filling of the artificial extrapleural space by a foreign substance, usually some variety of paraffin. The latter expedient has in great part been discontinued for reasons which I shall not here enumerate.

I found that if this extrapleural space were treated by packing it with gauze until there was well-established healing from the bottom,

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the chest wall would retract into the dead space and there would be permanent closure of the tuberculous abscess. But it occasionally happened that when the cavity was held patulous by rigid or even calcified tissues its walls could not be approximated by the method just described, even with the removal of long sections of rib and with total superior costectomy. In some of these cases after assuring oneself that there are firm adhesions between the visceral and parietal pleural layers, the tough wall may be incised down to the soft inner covering of the cavity and then direct compression becomes effective.[3]

My own method of apical or upper lobe extrapleural compression has the advantage of lessening the danger of the operation while producing in the four postoperative days a much larger extrapleural space than that which was made at the time of operation.[4] Briefly, the original element in this procedure is the firm packing of the artificial space over the tuberculous cavity with crumpled rubber dam a bit thicker than that employed in dentistry. This is held firmly in position by suturing the skin and muscle over it. Three to five days later the sutures are removed and the rubber dam is taken out. The space which it occupied will be found to have increased greatly in capacity so that the intrapulmonary cavity will have disappeared by the approximation of its walls. This is because of the constant elastic spreading of the packed rubber. After the removal of the dam, gauze packing is instituted until firm granulation is present when the gauze is omitted and the boneless parts of the chest wall will be drawn in. The operation may be modified by suturing the wound permanently at the time of operation, leading the end of the dam out through an opening left at the lowest part of the wound. At the termination of the three to five postoperative days the dam may be withdrawn and a very soft multifenestrated tube inserted, with external compressing pads placed upon the upper thoracic wall, to produce rapid retraction and healing. There is very little tendency for the mobilized lung to rise in the chest; on the contrary, it inclines to fall away, so that even the strain of coughing rarely brings it even for an instant to its former position in the dome of the thorax.

Studying the physics of this procedure it is realized that the resection of the first rib is not vital as it is in typical thoracoplasty, and that its undersurface makes a plane of firm counter pressure for the elastic packing outside the lung. The cavity within the lung would in any event be obliterated and held by firm scar tissue. Incidentally, the operation itself is shortened and there is less traumatism.

The comparative simplicity of this new thoracoplastic apicolysis is impressive. The danger to the subclavian vessels, especially the vein, is minimized, and the almost inevitable contusion of the brachial plexus during costectomy is prevented. It is unnecessary for me to dwell upon the painful neuritis which so often follows the resection and continues for weeks or months.

Kinsella,[5] in a paper read last July at the New York meeting of the American Association for Thoracic Surgery, advised subscapular packing as a secondary procedure when thoracoplasty had failed. I had been performing apicolytic thoracoplasty in most of my cases, at first with gauze, then with rubber dam, as a first stage of complete thoracoplasty, and it appears to me far more logical to continue this method than to wait for the possible failure of the more extensive operation. Now, with the simplified and more efficient way here described I believe that there will be fewer failures.

My cases are too few, five in all, to form an opinion on the effect of first rib preservation in preventing or minimizing the deforming upper scoliosis which at present is so common, and yet, judging by the imbal-

Fig. 1. Fig. 2.

Fig. 1.—X-ray film before operation.

Fig. 2.—After apicolysis with thoracoplasty; some months after operation. The first rib has dipped, but is present. Patient's condition excellent. (Case 1.)

ance which must result from removal of the upper rib, one may at least hope with reason that the maintenance of skeletal symmetry in the upper chest may modify the tendency to this deformity.

SALIENT POINTS OF HISTORIES

CASE 1.—F. J. M., aged thirty-two years, referred to me by Dr. Herben from Loomis Sanatorium, had been ill for ten years. There was copious expectoration. Report from Loomis is as follows:

"*Right*—heavy, fibrocaseous infiltration above the first interspace and sixth spine, enclosing a cavity measuring 2¼ × 3 cm. Large cavity posteriorly between the seventh and ninth ribs measuring 4½ × 7 cm. Flattening and moderate elevation of the diaphragm. Moderate retraction of the trachea.

"*Left*—Evidence of fibrotic deposits in the upper quarter and below the hilum. Pleural thickening toward the base with diphragmatic and costophrenic adhesions."

Very little improvement had followed artificial pneumothorax. Blood pressure maximum, 95. The patient was round-shouldered, amounting to an upper kyphosis. There was partial ankylosis of the right shoulder, which had apparently nothing to do with the tuberculosis, but had followed a tennis injury. Complete atrophy of the deltoid. Apicolytic thoracoplasty performed on April 11, the patient being but lightly anesthetized. Dr. Douglas of Loomis was present. The operation was extremely difficult on account of the kyphosis, and although I believed I had divided the first rib, it was clearly shown later on that the first rib was intact. This, in spite of corroboration by Dr. Douglas and others who were present. It lay in

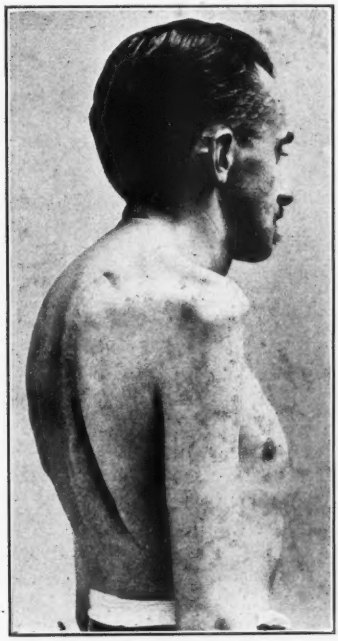

Fig. 3.—Photograph of patient to illustrate spinal curvature, almost kyphotic, and atrophy of right deltoid. Patient well and working. (Case 1.)

reality *below* the second. Four ribs, the second, third, fourth, and fifth, were resected, and rubber dam tense packing was carried out. The next rib below those resected was surrounded with a black silk thread to facilitate identification at the next stage. Dressing with gauze held under pressure by elastikon.

Two later operations were performed to complete the thoracoplasty. Without going into details, I may say that the patient went back to Loomis a month after his last operation, and has steadily improved. He is now working, and is symptomless. (Figs. 1, 2, and 3.)

CASE 2.—Miss E. S., aged thirty-three years, came to me Nov. 8, 1933, from Loomis Sanatorium. She had been ill for more than two years, and when admitted to Loomis there was a dense infiltration involving the left lung with an apical

cavity 2½ × 2½ cm. The expectoration was about 40 grams. Weight normal. No fever. In July, 1932, the induction of artificial pneumothorax was attempted, but satisfactory result was prevented by pleural adhesions.

Early in 1933, the left phrenic nerve was crushed by Dr. Douglas, and the diaphragm became elevated about 3 cm. above the average level. The sputum increased, then decreased, always positive on concentration. The nerve crushing was repeated about nine months later, but there was now persistent, active motion, although no accessory nerve fibers were found. The dense apical lesion with honeycombing was unaffected. There was some retraction of heart and trachea into the left hemithorax. Blood presure 145/90 when I first saw her, and there was some hoarseness of recent date. Operation Nov. 13, 1933. Electric scalpel. Typical apicolytic thoracoplasty, five ribs, the second, third, fourth, fifth, and sixth; but because of extremely dense adhesions, besides the rigidity of the lung itself, there were difficulties. I was able, however, to secure good collapse downward and mesially. Twenty-four hours after operation there was discomfort, but no pain. It was later found that in spite of what I had considered sufficient identification, the first rib had evidently *not* been resected. I have seen other samples of the flattening of the second rib which produced resemblance to the anatomy of the first.

Expectoration was greatly diminished, and was very scanty within two weeks of the operation. No tubercle bacilli on smear. One month after operation, x-ray picture revealed a fluid level. This was obviously extrapleural. I removed about 3½ ounces of pus by aspiration, a drainage opening was made, and a tube put in; the pus contained *no tubercle bacilli.* Films now confirmed resection of the left second to sixth ribs, with a large extrapleural cavity in the region corresponding. The entire left side below the resection was dense, and no differentiation was possible.

On Oct. 17, 1934, about a year after operation, Dr. H. M. Riggins wrote me that the patient, although otherwise without symptoms, had a small amount of sputum negative on concentration. No cavity was shown at this time in x-ray films made by him. In a subsequent personal communication from Dr. Riggins, he informed me that there had been some recurrence of extrapleural fluid.

CASE 3.—Miss W. M. S., aged twenty-two years, was referred to me by Dr. W. Atmar Smith of Charleston, S. C. She had been ill for some years with bilateral disease. The left lung broke down rather rapidly, and there was revealed by x-ray examination advanced glandular tuberculosis in the left hilum with extension into the lung field along the main interlobar fissure. There was a large left upper cavity, the dimensions of which had been the cause of its being mistaken for pneumothorax (Fig. 4). A left phrenic nerve operation was performed by another surgeon with some resulting elevation of the left diphragm and with a little decrease in the cavity. It was, however, still 2½ in. in its widest diameter. She was operated upon in April, 1935, the second, third, and fourth ribs having been resected with resulting change in the form of the diseased space, but with its actual contents probably not much reduced from the state before operation (Fig. 4). The general condition of the patient was good—temperature about 100°, more or less; anemic but well nourished. There were more than 2 oz. of positive sputum. I believed that a complete obliteration of the upper cavity would tend to improve the patient, and might even effect a cure. Accordingly, after her entrance into the Semi-Private Department of Mount Sinai Hospital on Nov. 9, and after a preliminary digitalization which raised the blood pressure from 117 systolic to 122 systolic, I operated Nov. 12, 1935, in the afternoon—so that the patient would have discharged much of the twenty-four-hour sputum. Dr. Branower administered a minimum dose of avertin, and continued with nitrous oxide and oxygen.

Procedure.—With the electric scalpel an incision was made along the original scar, and the scapula was dislocated forward. The second, third, and fourth ribs were resected, almost to the lateral processes of the vertebrae, and about 4 in. of the fifth rib were also taken away subperiosteally. By digital manipulation the lung was pushed downward, revealing the lower surface of the intact first rib, and a space about 2½ in. in its longest diameter was secured. It was packed with the crumpled rubber dam held in place by a piece of iodoformized gauze, and the wound sutured in two layers; the skin with silkworm gut. A small dressing was applied,

Fig. 4. Fig. 5.

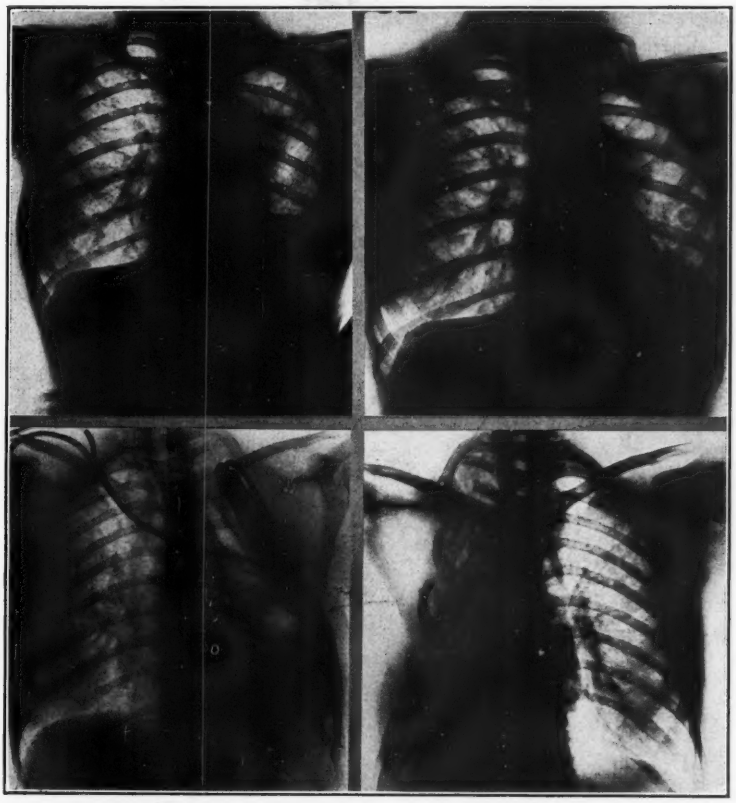

Fig. 6. Fig. 7.

Fig. 4.—Before operation.

Fig. 5.—After operation by another surgeon, at which time the first rib was not resected. (Left phrenic nerve had been interrupted) second, third, and fourth ribs resected by same surgeon. Little reduction in size of cavity, but its form changed. In the lower lobe will be seen a small additional cavity.

Fig. 6.—Extrapleural cavity marked by a tube filled with sodium iodide passed into the drainage opening. The lower lobe cavity much larger.

Fig. 7.—Final obliteration of lower cavity. A mere slit remains of the great upper one. See history. (Case 3.)

and the arm and shoulder were drawn well backward and held there. Elastikon was applied for additional compression, in such a manner as not to affect the motions of the healthy side. Loss of blood was moderate. A few days later, however, the

hemoglobin was found to be 50 per cent, and a small transfusion was given by Dr. Rosenthal. After operation the cough was still present but moderate, and the expectoration also. A few days later, the packing having been removed and a large soft tube inserted, I outlined the cavity with a drainage tube filled with sodium iodide solution. The resulting film (Fig. 6) revealed a very great improvement in the reduction of the capacity of the pulmonary cavity. Indeed, it is little more than a wide slit. Later in the course of the disease, another transfusion of 500 c.c. was made. The cough became almost negligible, and there was excellent collapse. About

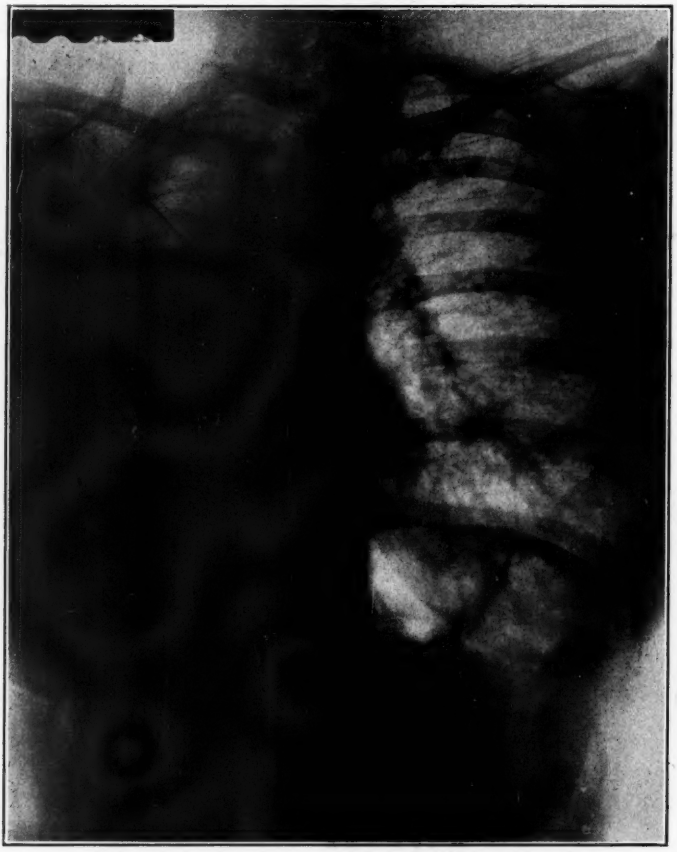

Fig. 8.—Before operation, large right upper cavity. Trachea and bronchi strongly drawn to the same side. Lower part of picture opaque, even to long exposure, and cannot be read. See history.

three weeks after the apicolysis, it was noted that a tiny shadow probably in the lower lobe, apparently representing a small cavity, which had been seen in one of the previous films, had increased in size, and taken the appearance of a circular area at least 1½ in. in diameter, extending from just above the seventh rib to just below the eighth. It is clearly demonstrated on lateral view as well. I therefore resected the four ribs below the upper resection, and succeeded in obliterating the cavity. This was accomplished in two stages (Fig. 7).

On Dec. 27, six weeks after operation, the sputum, about half an ounce in all, was negative on smear for the first time. She was discharged on Jan. 3, and I have received enthusiastic reports from her since then.

CASE 4.—Mrs. E. G., thirty-nine years old, with one son, aged nineteen years, had been ill with bilateral tuberculosis for more than three years, and had been bedridden nearly the entire time. Her husband is said to have had tuberculosis, but is now reported well. She was referred to me by Dr. Schultz of Columbia Sanatorium, Philmont, N. Y., who sent me the x-ray pictures for examination, and who also gave a brief history of the case which need not concern us here. At the time of her admission in 1932, her disease was far advanced, with exudative and fibrocaseous disease of the right upper and middle lobes, and a small tuberculous area in

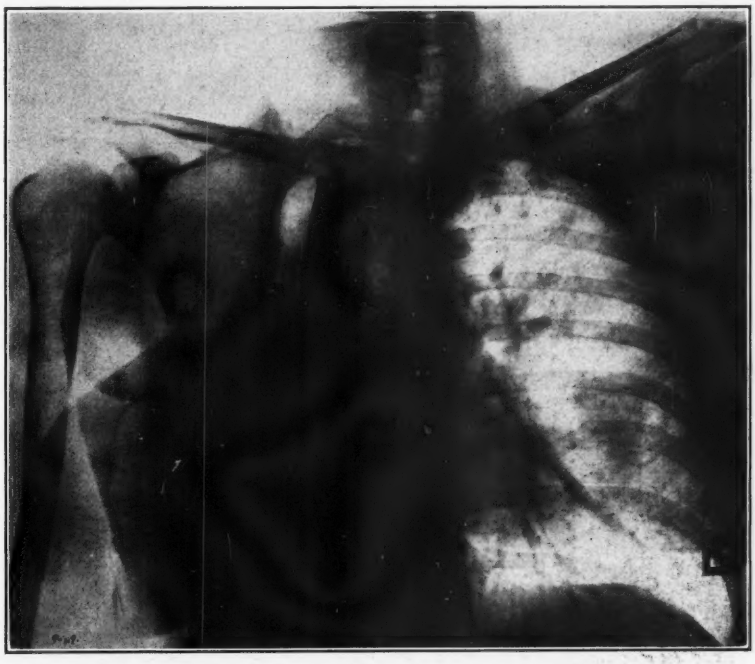

Fig. 9.—After first operation. See history. Opaque rubber tube temporarily in place for identification of extrapleural cavity. The light area alongside is also extrapleural. Position of trachea and bronchi very greatly improved. (Case 4.)

the left apex. When I saw her pictures, there was a very large cavity in the right apex, the remainder of the right chest being opaque (thickened pleura?) so that details could not be made out even with the aid of Bucky's grid. This condition was evidently an aftermath of an unsatisfactory artificial pneumothorax. For a time she had been extremely ill, but had gradually improved, and gained 38 pounds since her admission to the Sanatorium, three years before. Sputum *always positive,* and the quantity from 10 to 16 grams per day. For the past year, no elevation of temperature. Hemoglobin 85 per cent. Faint trace of albumin in the urine.

In addition to the roentgen signs already mentioned, the trachea and bronchi were dislocated by traction as far to the right as in any case which I had ever seen (Fig. 8). I concurred with Dr. Schultz's opinion that thoracoplasty should be

performed. Before the operation I informed the husband and also the patient that I did not intend to resect the first rib. On Monday, Feb. 3, under avertin anesthesia by Dr. Branower, I operated. Dr. Schultz was present and predicted that I would have a difficult time on account of the induration of the tissues.

Procedure.—Incision with the electric scalpel from just below the spine of the right scapula downward about 1½ in. from the spinous processes, curving obliquely forward below the angle of the scapula. Hemorrhage was much more profuse than is usual in this operation, and several vessels had to be ligated in addition to the usual electric coagulation. I resected about 3 in. of the third rib, a little less of the second, then removed sections of the fourth and fifth, a total of 14½ in.

It required very great physical force to attain an extrapleural, extrafascial space of about the size of a small orange. It was even necessary to divide by sharp dissection a few tough adhesions above. This extrapleural cavity was firmly packed with rubber dam, crumpled and overlaid with a single thin gauze pack, the gauze and end of the rubber dam protruding from the lower part of the wound. In placing the rubber dam packing in position, it was a great help to have the firm backing of the lower

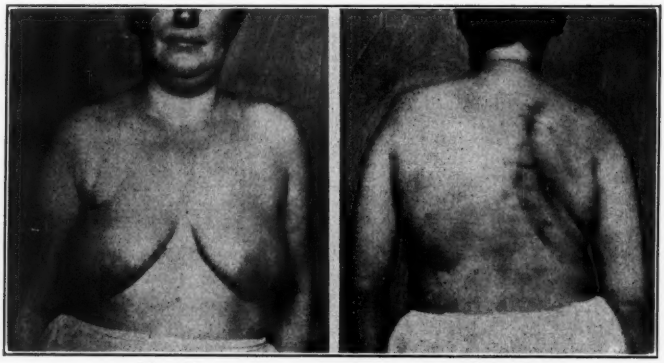

Fig. 10. Fig. 11.

Figs. 10 and 11.—During convalescence. (Case 4.)

surface of the first rib. The wound was then sutured with chromicized catgut through all the deep tissues, and a few silkworm gut sutures were taken through the skin.

Postoperative course was most satisfactory. No nerve pains running down the arm, and very few complaints. An x-ray picture with the packing in place three days after the procedure, showed not only the great size of the extrapleural cavity, but also the return of the trachea and main bronchial division almost to the midline. The packing was removed four and one-half days after operation by withdrawing it from its place of exit, and a soft black tube replaced it. Nine days after the operation I inserted a long piece of opaque narrow rubber tube into the black tube, and the x-ray picture then revealed the trachea still in good position, although showing a slight tendency to slip back, and the extrapleural cavity distinctly smaller than it was; not because of lung expansion but, it seemed to me, on account of the falling in of the chest; which I had tried to hasten by the use of elastikon over an axillary packing. The heart was still displaced, and the lower part of the chest was opaque to x-ray. (See Fig. 9.)

In spite of the handicap of an opaque lower chest, I decided upon the advisability of completing the thoracoplasty, because of the history of lower cavities. The

operation was done on Feb. 20, seventeen days after the first stage. The incision for the second operation will be noted in Fig. 11. From the sixth to the tenth ribs inclusive were resected, and although there was considerable bleeding as in the former operation, it was never alarming. The anesthesia here was also by avertin. An interesting note by the patient is that the pain was less than that following the first operation, and this may perhaps have been because I had laid a strip of gauze soaked in novocaine solution into the wound, letting it protrude below. After the first operation, there had been slight blood streaking of the sputum, and this continued after the second, but ceased twenty-four days after the first stage. The amount of sputum increased somewhat, and was from 8 to 10 c.c. of thick, tenacious greenish mucus in twenty-four hours. The heart at this time began to swing to its normal position. Trachea still slightly deviated. Patient felt well, and exactly one month after the operation the sputum for the first time contained no tubercle bacilli on smear. A few days later the *concentration test was also negative.* The amount has decreased to 3½ c.c. She was discharged about six weeks after the operation. The photographs made by me in the hospital ward give a good idea of the degree of deformity with dropping of the shoulder (Figs. 10 and 11).

CONCLUSIONS

1. In apicolytic thoracoplasty the first rib need not be resected.
2. The operation by the method here described is simpler and more efficient than that in which the rib is resected.
3. Injury to important vessels and nerves is minimized.
4. The consummation of apical collapse is as perfect as with first rib resection.
5. Postoperative scoliosis of the upper portion of the spine may be minimized.

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PHRENIC INTERRUPTION IN THE TREATMENT OF PULMONARY TUBERCULOSIS*

A Five-Year Study and Follow Up

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IN THE quarter of a century since the introduction of simple section of the phrenic nerve for the treatment of pulmonary tuberculosis an extensive literature has accumulated covering the various technical and clinical problems that have since arisen. The variation in the origin and distribution of the nerve and its accessory branches thoroughly worked out particularly by the Matsons[1] has served to explain many of the early failures to obtain paralysis of the hemidiaphragm and has pointed to modifications in the operation by which the number of paralyses has been tremendously increased. Changes in vital capacity and in venous pressures, the probable causes of the "gastrocardiac complex" and immediate postoperative complications of operations on the phrenic nerve described by one of us[2] have come in for their share of investigation; and, although differences of opinion exist as to the mechanism of some of these changes, their study has served as a warning that the operation should be approached with greater thought of possible undesirable postoperative sequelae. As interesting as these problems are, their further consideration is not within the scope of this paper.

When one analyzes the hundreds of reports on indications for phrenic interruption, a still wider difference of opinion exists—so much so, that one is at a loss to know for what type of case the operation is suitable, particularly when it is considered as a sole procedure for parenchymal tuberculosis. Appreciating the need for clarification on this point, we propose to relate our findings and conclusions as based on 95 cases followed from six months to four and one-half years after operation, the vast majority having been observed for no less than two years.

The plan of this study is guided by general principles concerning a diagnosis and treatment discussed more fully elsewhere.[3] No lesion was classed in the cavernous group unless cavity obviously existed. If any doubt arose, roentgen studies of the Potter-Buckey type or films in various angles, often supplemented by convincing contrast medium roentgenograms and careful sputum examinations, were resorted to before a diagnosis of the presence of cavity would be made.

*From the Hudson County Tuberculosis Hospital and Sanatorium. Dr. B. S. Pollak, Medical Director.

Read before the clinical session of the Tuberculosis Sanatorium Conference of Metropolitan New York, April 8, 1936.

For reasons given in the paper referred to,[3] the infiltrative and infiltrative-cavernous lesions in which the existing cavity measured 2 cm. in diameter or less were not collapsed unless progression, ulceration or failure in reduction of size of cavity was noted on bed rest regime. Patients presenting an infiltrative-cavernous process in which the cavity was larger than 2 cm. were subjected to collapse measures either immediately or after a reasonable trial period of rest, depending upon such factors as duration of illness, size, location and character of wall of cavity, character and degree of pericavernous changes, previous management of disease particularly with regard to supervised bed rest, etc. When collapse therapy was indicated, pneumothorax was the procedure of choice in all cases, the other measures being reserved for those on whom the former had failed either because of lack of a free pleural space or because of the presence of offending adhesions that could not be cauterized or sufficiently relaxed by supplementary phrenic interruption or thoracoplasty to result in an effective collapse. We prefer pneumothorax as an initial measure in any collapse therapy program because it, when free of interfering factors, is the simplest and the most direct, and productive of the greatest number of effective collapses.

It will be evident from a review of these principles and from reference to Table I that ample time was given for spontaneous closure of cavity to take place before phrenic interruption.

TABLE I

INTERVAL BETWEEN ADMISSION AND PHRENIC INTERRUPTION IN 68 CASES

LESS THAN 5 MONTHS	5 MONTHS TO 1 YEAR	1 TO 2 YEARS	OVER 2 YEARS
14	31	17	6

Therefore it may be reasoned that favorable or unfavorable results following operation should more or less directly, and in part at least, be accredited to the resulting hemidiaphragmatic paralysis and the accompanying changes.

The postoperative care consisted of continuation of the preoperative regime with frequent fluoroscopic and x-ray observations and careful sputum studies. Graduated exercises were permitted after closure of cavity had taken place as revealed on the roentgen film. After discharge from the hospital, patients were examined by the same group of examiners at intervals of one to three months along lines similar to those practiced during residence in the institution.

Of the 95 cases discussed in this report, 68 fall into the group wherein phrenic operation was used solely for the treatment of parenchymal tuberculosis of the cavernous or infiltrative-cavernous forms.

In all, pneumothorax had been attempted and was abandoned either, as in the vast majority, because of lack of a free pleural space or because of extensive adhesions. In retrospect, this latter group can be divided into two categories:

1. Cases in which the lesion is of such nature that one may expect either an unfavorable or no change to follow hemidiaphragmatic paralysis (30 cases).
2. Cases in which the parenchymal changes are such that various degrees of favorable results may be expected following the operation (38 cases).

CONTRAINDICATIONS

We believe that lack of knowledge of the contraindications for phrenic interruption is the simple explanation for O'Brien's[4, 5] en-

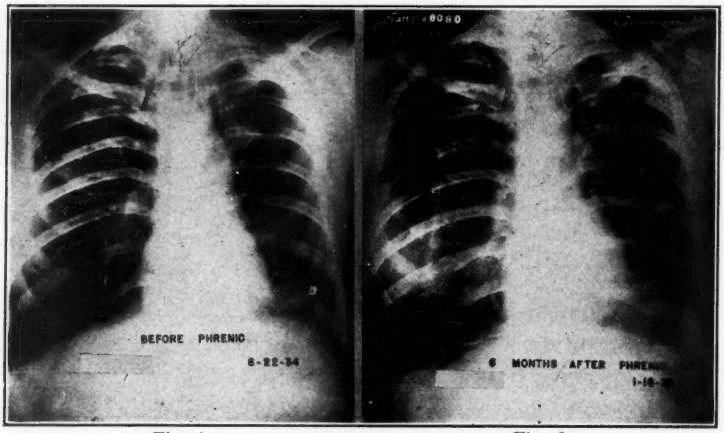

Fig. 1. Fig. 2.

Fig. 1.—J. S., male, aged twenty-four years, entered hospital February, 1933, complaining of loss of weight and productive cough. Tubercle bacilli found in sputum. X-ray examination revealed bilateral productive cavernous tuberculosis of right upper lobes, more extensive in left upper lobe. Pneumothorax was attempted first on the left where no free pleural space could be found. The right-sided cavity was obliterated by a partial collapse of the lung. General condition of patient improved, but because of persistent positive sputum, the left phrenic nerve was interrupted on June 2, 1934.

Fig. 2.—Same patient six months after temporary interruption of the left phrenic nerve. Note moderate elevation of the corresponding hemidiaphragm but no change in size of large cavity.

thusiasm, for Coryllos'[6] pessimism, and for the "hit and miss" attitude for this procedure on the part of many phthisiologists. It can readily be seen how favorable results will multiply almost unbelievably when lesions either in the stage of spontaneous resolution or having the capacity to heal on bed rest regime are managed by some form of operation on the phrenic nerve. Likewise it is not difficult to appreciate the discouraging reports of those who follow the dictum of the Matsons[1] who state:

"In the tuberculous diseases of the lung operative procedures on the phrenic nerve are indicated as an independent procedure in all

cases wherein artificial pneumothorax is indicated and wherein adhesions have prevented the introduction of gas, or wherein adhesions of the inoperable type prevent the establishment of a satisfactory collapse." It is urgent, therefore, to indicate clearly the type of tuberculous pulmonary changes which for one reason or another cannot be managed by pneumothorax and must, if other conditions permit, be handled from the start by more radical surgical procedures other than severing of the continuity of the phrenic nerve.

1. *Huge Cavities.*—A large cavity occupying the entire apex or at times part or whole of the lobe with its walls firmly adherent to the parietes of the chest cannot be expected to be benefited by the limited relaxation resulting from a paralyzed hemidiaphragm. It is well known that even with extensive thoracoplasty such cavities consisting of nothing

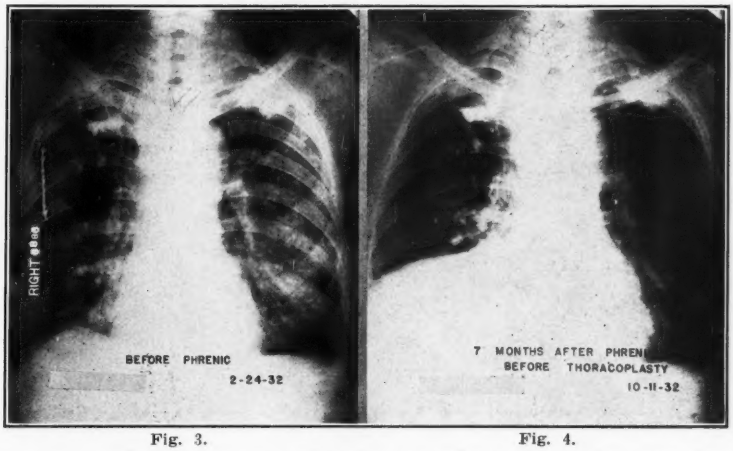

Fig. 3. Fig. 4.

Fig. 3.—L. S., male, aged forty-nine years, admitted December, 1931, with symptoms of loss of weight, cough and expectoration. Sputum found positive, and slight afternoon fever was recorded. X-ray examination showed a bilateral infiltrative process and a cavity in the right upper lobe. Pneumothorax was attempted on the right, but no free pleural space could be found. Patient remained in bed for the next fifteen months, showing progressive clinical improvement but little change in the lesion, which was characterized at this time, as seen in the film, by the presence of a thick-walled cavity in the right upper lobe, scattered dense nodules throughout both lungs, and a fibrous patch in the left apex.

Fig. 4.—Same patient seven months after permanent interruption of the right phrenic nerve. Note that the cavity was not influenced, although good rise of the hemidiaphragm had taken place.

more than a shell formed by thickened pleura resist collapse. In fact, there is a definite potential danger in the use of the operation in such cases if the pericavernous infiltrate is of the caseous type or when expectoration is profuse, for the paradoxical respiration which follows may serve to "massage" the contents of the cavity or the exudate about it into the opposite lung and bring about a fatal fulminating caseous bronchopneumonia (Figs. 1 and 2).

2. *Thick-Walled Cavities and Cavities Embedded in a Fibrous Infiltrate.*—Even with a good or marked rise of the diaphragm we have not encountered a single instance of closure of a cavity presenting a clear-cut dense fibrotic wall or a dense pericavernous infiltrate confluently arranged. There is little wonder when one considers these failures in the light of postmortem studies of patients presenting such lesions, particularly of those who met with death following thoracoplasty. The involved portions of the lung or lungs in such individuals reveal a firm consistency due to the hard infiltrate surrounding the cavity whose walls resist approximation even by manual compression. Added to these factors is the resistance to collapse exerted by the thick-walled dilated bronchi which we have found to be present about the cavity almost universally as shown by bronchographic studies before and/or after death[7, 8] (Figs. 3-6).

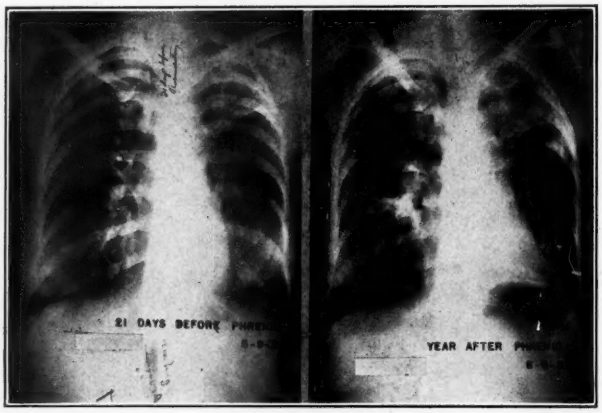

Fig. 5. Fig. 6.

Fig. 5.—A. V., female, aged twenty-six years, admitted August, 1931. Symptoms and signs were those of productive cough, loss of weight, and afternoon fever. Sputum positive. The pathologic changes were those of a fibrocavernous tuberculosis confined to the left upper lobe and mottled dense minute foci in the apex of the left lower lobe and in the right upper lobe. Pneumothorax failed because of an obliterated pleural space. Patient continued on bed rest but showed little improvement except for loss of fever. Left phrenicotomy performed June, 1932.

Fig. 6.—Same patient one year after phrenicotomy. Note that cavitation progressed and in addition a bronchogenic extension to the right lung had taken place.

3. *Peripherally Located Adherent Cavities.*—These cavities can be seen on the anteroposterior film to be situated either along the outer zone of the lung field or in the apex subpleurally. They have part of their circumference firmly adherent to the parietal pleura. Even when of moderate size and relatively thin walled and having little or no surrounding changes, such cavities resist collapse by paralysis of the diaphragm (Figs. 7-10).

4. *Lesions Within a Lung Surrounded by a Thick Pleura.*—The cases falling in this group are another cause for disappointment. The pleural fibrosis almost always extends to the diaphragm, resulting in

partial or complete fixation of the latter. In not a few instances paradoxical motion of the affected diaphragm can be elicited. Little more can be expected from phrenic interruption, and, according to Lambert,[9] even if added relaxation is obtained, "Eccentric tension forces arise from the partial collapse whereby the fibrous strands acting from their fixed points on the parietes actually tend to pull apart the walls of the cavity and prevent its collapse." (Figs. 11 and 12.)

Fig. 7. Fig. 8.

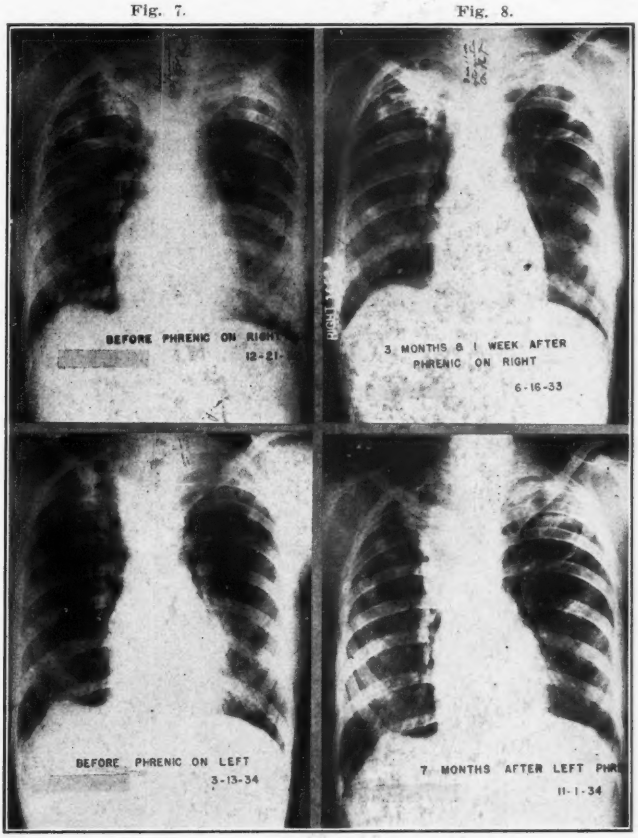

Fig. 9. Fig. 10.

Fig. 7.—H. G., female, aged twenty-two years, admitted June, 1932, complaining of productive cough. Sputum positive. X-ray examination revealed a bilateral productive cavernous tuberculosis confined to the upper lobes. Pneumothorax was attempted but no free pleural space was found on either side. After six months of bed rest a right-sided phrenicotomy was performed Jan. 25, 1933, but no paralysis of the hemidiaphragm followed. A second attempt was made on March 6, 1933, resulting in paralysis of the diaphragm but no rise.

Fig. 8.—Same patient three months after right phrenicotomy. Note that small cavity in the second interspace was obliterated but larger cavity adherent to the axillary pleura remained unaffected.

Fig. 9.—Same patient just before left phrenic interruption for cavity beneath the clavicle. The cavity was surrounded by a thick pleural cap.

Fig. 10.—Same patient seven months after left phrenicectomy. Cavity remains unchanged.

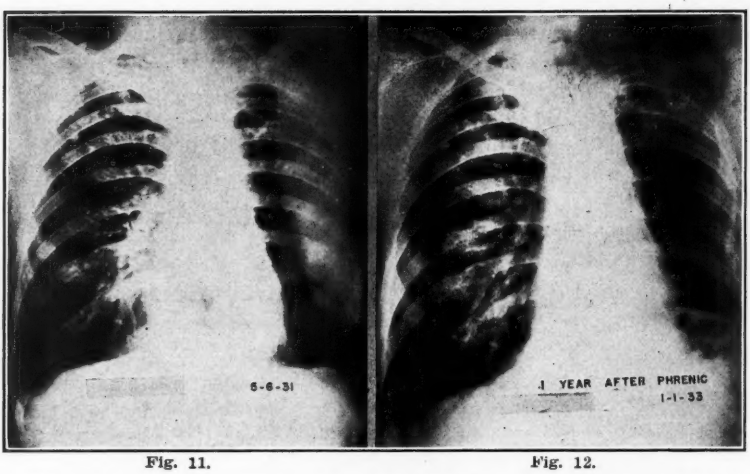

Fig. 11. Fig. 12.

Fig. 11.—S. M., male, aged thirty-five years, admitted July, 1928, complaining of productive cough and frequent hemorrhages. Sputum positive. X-ray examination revealed (essentially about as seen in the film of 1931) a cavernous process in the left upper lobe and a thickened pleura and calcified nodules mottled throughout the right lung. Pneumothorax was not even attempted because of the thick pleura. Although the patient was in good condition for thoracoplasty, a permanent left phrenic interruption was performed Jan. 6, 1932.

Fig. 12.—Same patient one year after phrenicectomy. Note that cavity remains patent, although a fair rise of the diaphragm followed the operation. Cavity finally obliterated by thoracoplasty.

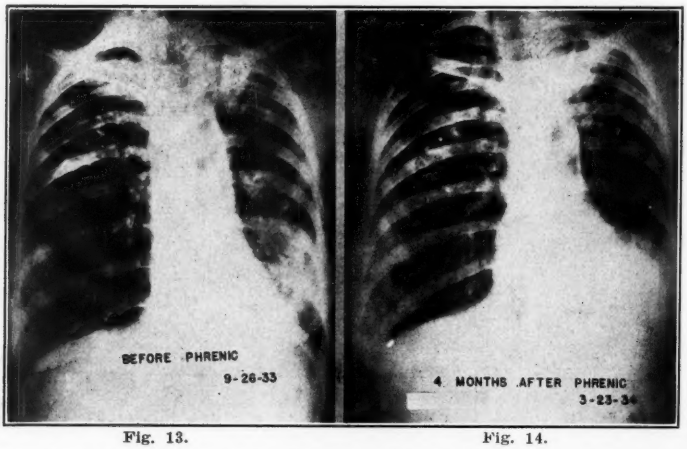

Fig. 13. Fig. 14.

Fig. 13.—J. M., female, aged twenty-one years, admitted April, 1933, from another clinic where she had been receiving pneumothorax on the right side for a cavernous lesion in the upper lobe. Symptoms were cough and expectoration. Sputum positive. The x-ray examination showed a productive process in the left upper lobe in which multiple small cavities were present. Pneumothorax was attempted but no free pleural space was obtained. After a trial period of bed rest a phrenicectomy was performed Nov. 26, 1933.

Fig. 14.—Same patient four months after phrenicectomy. Note good rise of left hemidiaphragm and conglomeration of multiple cavities to form one large cavity. This change was accompanied by marked clinical activity and finally death.

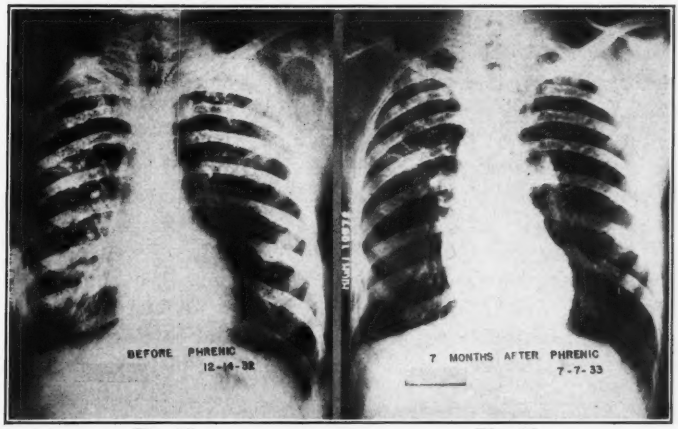

Fig. 15. Fig. 16.

Fig. 15.—J. M., male, aged twenty-two years, admitted February, 1932. Symptoms were cough, expectoration, and loss of weight. Sputum positive. X-ray examination revealed predominantly a right-sided lesion of an infiltrative cavernous type. Pneumothorax was attempted but no free pleural space was obtained. Patient was continued on bed rest until December, 1932, when a temporary interruption was performed because of no change in the lesion as shown in the film and characterized by the presence of a small cavity surrounded by mottled infiltrate.

Fig. 16.—Same patient seven months after right phrenicotomy. Note obliteration of cavity and marked resorption of the infiltrate in the absence of a rise in the hemidiaphragm although paralysis, as determined fluoroscopically, was present.

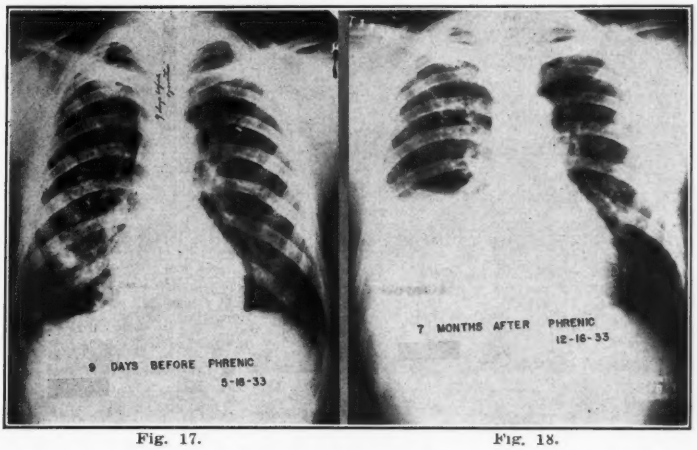

Fig. 17. Fig. 18.

Fig. 17.—G. K., male, aged twenty-one years, admitted March, 1933, complaining of cough and expectoration. Sputum positive. X-ray examination revealed a right lower lobe infiltrative ulcerative tuberculosis. Pneumothorax was attempted but no free pleural space was obtained. After a trial period of bed rest of about two months, phrenicectomy was recommended because of persistent positive sputum and progression of lesion.

Fig. 18.—Same patient seven months after phrenicectomy. Note complete obliteration of ulceration areas. Sputum at this time negative and patient free of symptoms.

5. *Multiple Cavities.*—The presence of multiple cavities, small or large, should contraindicate phrenic operation, for, invariably, at least in our experience, the resulting limited relaxation favors coalescence. While this is true, too, of pneumothorax, as already pointed out by Lambert,[9] nevertheless, the greater relaxation possible with the latter procedure, particularly in the absence of offending adhesions, more often than not brings about an effective collapse of the coalesced cavities not possible with the former method (Figs. 13 and 14).

INDICATIONS

Upon a comprehension of the contraindications, the indications for induced paralysis of the diaphragm can be stated more briefly. One should expect favorable results in small or moderate sized cavernous lesions with a surrounding zone of lung tissue more or less free of

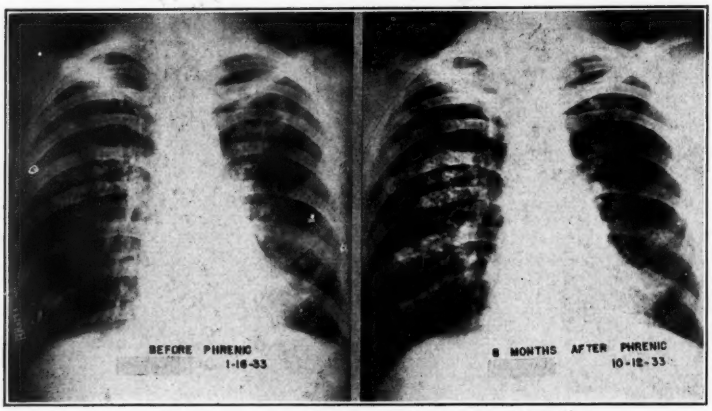

Fig. 19. Fig. 20.

Fig. 19.—R. B., male, aged twenty-three years, admitted September, 1932, complaining of cough and expectoration, anorexia, and loss of weight. Sputum positive and fever 101° to 103°. The x-ray examination revealed a mixed cavernous process in the left upper lobe. Pneumothorax was attempted on the left but no free pleural space was obtained. Bed rest was continued until January, 1933, when, because of general clinical improvement and loss of fever, phrenic interruption was recommended.

Fig. 20.—Same patient eight months after a temporary left phrenic interruption. Note complete obliteration of the soft-walled cavity (surrounded by more or less normal lung tissue) which was present before operation.

infiltrate. A cavity within a shrinking lobe which has ceased to contract further is an indication, provided the infiltrative process about the cavity is not extensive and provided the latter has shown diminution from the original size along with the contraction of the lobe. We cannot affirm the enthusiasm of Slavin[10] that midlung region cavities, centrally located, respond favorably to phrenic interruption. It has been our experience that such cavities frequently resist collapse with any of the surgical procedures. A careful study of Table II and the illustrations will serve to indicate more clearly the type of case for which the operation is suitable. (Figs. 15-31.)

TABLE II

CHARACTER OF LESION IN 20 SUCCESSFUL CASES OF PHRENIC INTERRUPTION

1. Cavity (2.5 cm.) in the right apex and surrounding zone relatively free of disease.
2. Cavity (2.5 cm.) with pericavernous infiltrate in the right upper lobe.
3. Right upper lobe reduced in volume and within it a 2 cm. cavity. Mixed cavernous lesion in the left upper lobe.
4. Bilateral productive nodular infiltrate in the upper lobes. Right upper lobe is shrunken and within it is present a small cavity (1.5 cm.).
5. Cavity (3 cm.) in diameter in right apex—surrounding zone relatively free of disease.
6. Small cavity (1.5 cm.) in the right first interspace and scattered productive foci throughout the upper lobe.
7. Productive cavernous process (3 cm.) of the right upper lobe.
8. Mixed ulcerative lesion in the right lower lobe.
9. Bilateral upper lobe productive infiltrate—more extensive in the left lung where there are high light shadows in the apex.
10. Cavernous process (3 cm.) in the right apex. Surrounding zone free of disease.
11. Cavernous lesion (3.5 cm.) in the left upper lobe and no pericavernous infiltrate.
12. Cavernous lesion (2.5 cm.) with no pericavernous infiltrate in the left upper lobe.
13. Productive cavernous infiltrate in the left upper lobe which is reduced in volume.
14. Mixed cavernous infiltrate in the left lower lobe. Moderate sized cavity in the upper lobe.
15. Partly shrunken right upper lobe within which there is a small cavity. Also moderate sized cavity in the left midlung region.
16. Mixed ulcerative process in the left upper lobe.
17. Bilateral upper lobe productive process and small cavity in the left first interspace.
18. Mottled cavernous process of the entire right lung and moderate sized cavity beneath the clavicle.
19. Mixed cavernous process left upper lobe and moderate sized cavity extending from apex to the first interspace in the outer zone. Scattered foci throughout the rest of the lung and in the right upper lobe.
20. Cavity (2.5 cm.) in the left upper lobe and scattered nodules in surrounding zone.

RESULTS

When the literature is reviewed so far as results are concerned, one finds much to be desired. In the first place, many of the recorded results are based on the classification of the National Tuberculosis Association and, for this reason, are not clear because they fail to define the lesion as to its character, location and perifocal changes prior to operation. In the second place, fully as many reports deal almost wholly with the postoperative effects with regard to subjective and objective symptoms and signs, the presence or absence of bacillary sputum, capacity for work, etc., but reveal little as to the morphologic changes in the lesion.

Now, as valuable as such statistics may be, they fail to convey the success of the operation if judged by closure of cavity or cavities shown on x-ray supplemented by repeated careful sputum studies revealing the absence of tubercle bacilli. Moreover, the vast majority of available reports indicate follow-up observations of relatively short intervals. If cases are followed for a longer time and if, likewise, in our opinion, the lesion is not arrested, symptoms will return.

From Table III it will be seen that of 38 suitable cases, closure of cavity was obtained in 20. It will be noted further that in 12 of the 20 the postoperative period of observation was three to five years, with

an average for the entire group of about three years. For reasons to be discussed later the cavity reopened in 2 with resumption of motion of the paralyzed hemidiaphragm. Restated, in approximately 47 per cent of the suitable cases or 29 per cent of the entire group the cavity remains closed.

Another interesting feature in connection with this study is that 5 patients improved sufficiently to warrant a plastic operation which had not been possible because of poor general condition prior to phrenic

Fig. 21. Fig. 22.

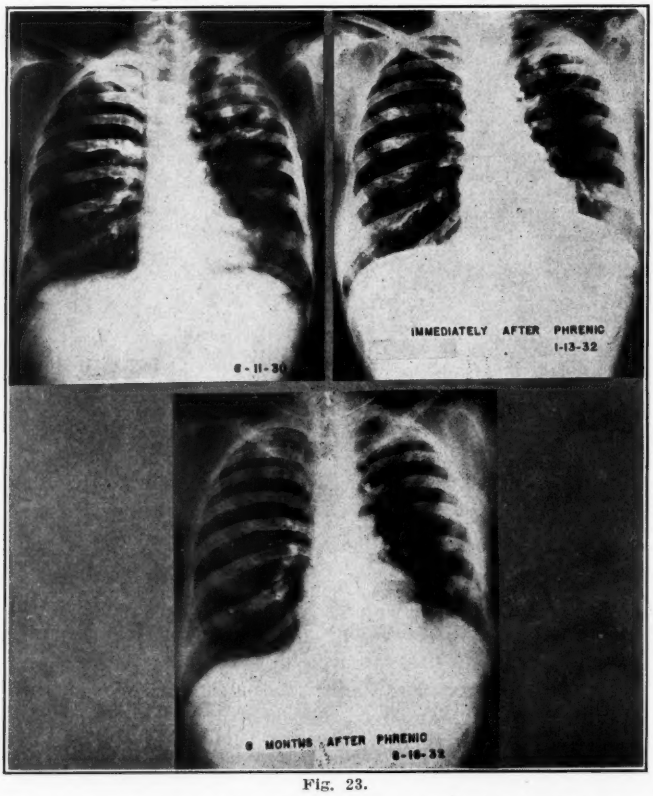

Fig. 23.

Fig. 21.—A. R., female, aged twenty-seven years, admitted June, 1931. Symptoms were productive cough, loss of weight, and fatigue. Temperature moderately elevated and sputum positive. X-ray examination showed a cavernous tuberculosis of the left upper lobe in which two large cavities were present. Pneumothorax was tried in July, 1931, but a free pleural space could not be found.

Fig. 22.—Same patient immediately after permanent left phrenic interruption. Note the lonesome cavity surrounded by normal lung tissue. The lesion before operation was essentially the same but cannot be shown because the film has been lost.

Fig. 23.—Same patient eight months after phrenic interruption. At that time the cavity was completely obliterated, the sputum negative and the patient ambulant.

interruption. In these cases there was noted not only a reduction in size of the cavity but also an accompanying gradual loss of signs of activity plus a gain in weight. While we do not advocate the proce-

TABLE III

RESULTS IN 38 SUITABLE CASES FOR PHRENIC INTERRUPTION

CAVITY CLOSED	CAVITY REDUCED IN SIZE	CAVITY UNAFFECTED
20	12	6

PERIOD OF POSTOPERATIVE OBSERVATION IN CAVITY CLOSED GROUP

6 MONTHS TO 1 YEAR	1 TO 2 YEARS	2 TO 3 YEARS	3 TO 4 YEARS	4 TO 5 YEARS
1	6	1	8	4

dure unless definite indications as described above exist, nevertheless we would suggest that, in borderline cases, not good risks for thoracoplasty, a temporary interruption may turn the tide for the patient and make thoracoplasty possible (Figs. 32 and 33).

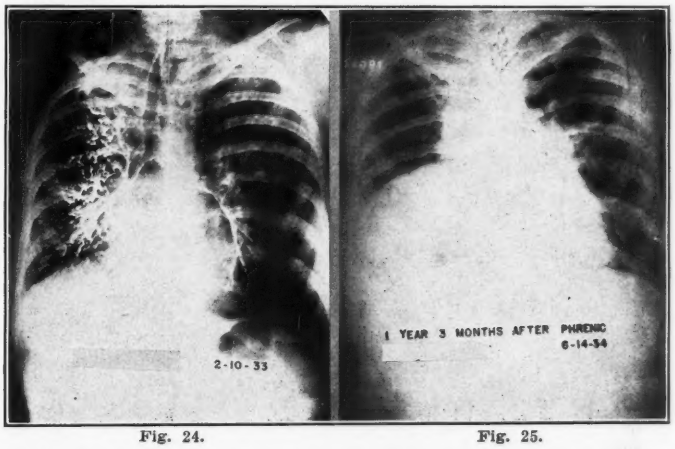

Fig. 24. Fig. 25.

Fig. 24.—E. S., female, aged twenty-seven years, admitted February, 1933, complaining of loss of weight, cough, and expectoration. Sputum positive. She had been on bed rest at home under the supervision of a physician for several months before admission. The lesion consisted of a moderate-sized cavity beneath the right clavicle as shown in contrast medium film. Pneumothorax was immediately attempted, but no free pleural space was obtained. Because the patient had had supervised bed rest, phrenicotomy was recommended without resorting to further expectant treatment.

Fig. 25.—Same patient one year and three months after permanent interruption of the right phrenic nerve. Note complete obliteration of the cavity.

Finally, another point should be considered along with these results, namely, the number of patients that may be spared the more radical procedure of thoracoplasty. In the series quoted, 6 patients who were good risks for a plastic operation obtained an effective collapse of their cavities by diaphragmatic paralysis. Furthermore, our experience with thoracoplasty in 9 phrenic failures indicates immediate postoperative closure in about 55 per cent and a death rate of 11 per cent.

Incidentally these results are identical with those obtained in a much larger series of cases which came to thoracoplasty directly. In view of these experiences one cannot justly advocate thoracoplasty in all

suitable cases that fail to respond to pneumothorax without separating those in which the simpler procedure of phrenic interruption may serve equally well.

It may be argued that the results cited are based on an insufficient number of cases observed. While this is true, it should be remembered that the findings of Nehil and Alexander[11] in a very large series of cases closely corroborate those of ours.

Fig. 26. Fig. 27.

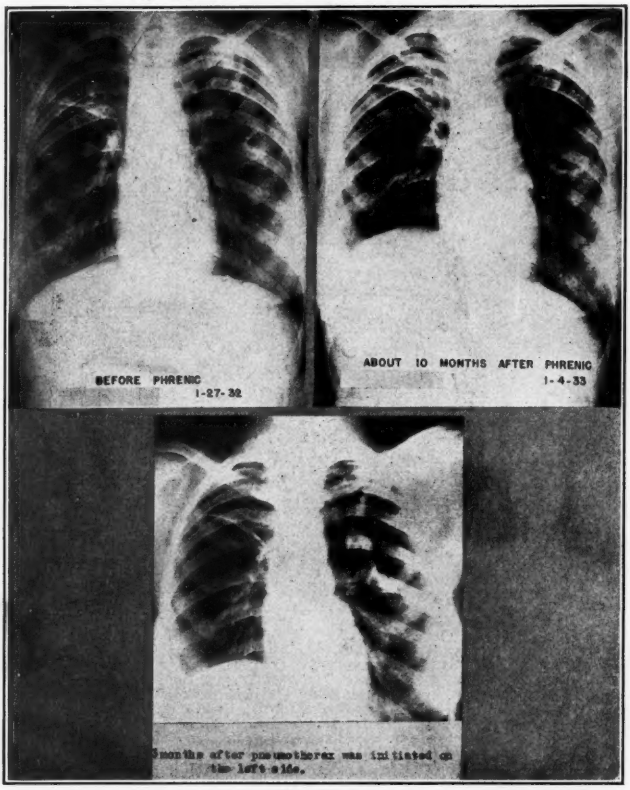

Fig. 28.

Fig. 26.—T. P., female, aged twenty-three years, admitted Feb. 5, 1931, complaining of loss of weight, cough, and expectoration. Sputum positive. X-ray examination showed a bilateral cavernous tuberculosis, the cavity in the right lung being in the upper lobe and that of the left in the midlung region. After several months of bed rest, pneumothorax was attempted on the right, but no free pleural space could be obtained. Phrenicectomy was recommended, and was performed on March 9, 1932.

Fig. 27.—Same patient about ten months after permanent right phrenic interruption. Note complete closure of the cavity and enlargement of the cavity in the left lung.

Fig. 28.—Same patient after effective collapse of the left cavity by pneumothorax.

Before leaving the discussion of the phrenic nerve operation as an independent measure, it may be well to consider certain questions previously raised, yet requiring further analyses because still disputable.

It may be asked what correlation exists between favorable results and the degree of rise of the diaphragm. Matson[1] states: "The beneficial influence of an induced hemidiaphragmatic paralysis is ascribed to the collapse of the diseased lung tissue affected by the rising diaphragm rather than to the rest provided. This conclusion is based upon the observation that the most satisfactory results were seen in those cases presenting a high diaphragmatic rise whereas the worst results were

Fig. 29. Fig. 30.

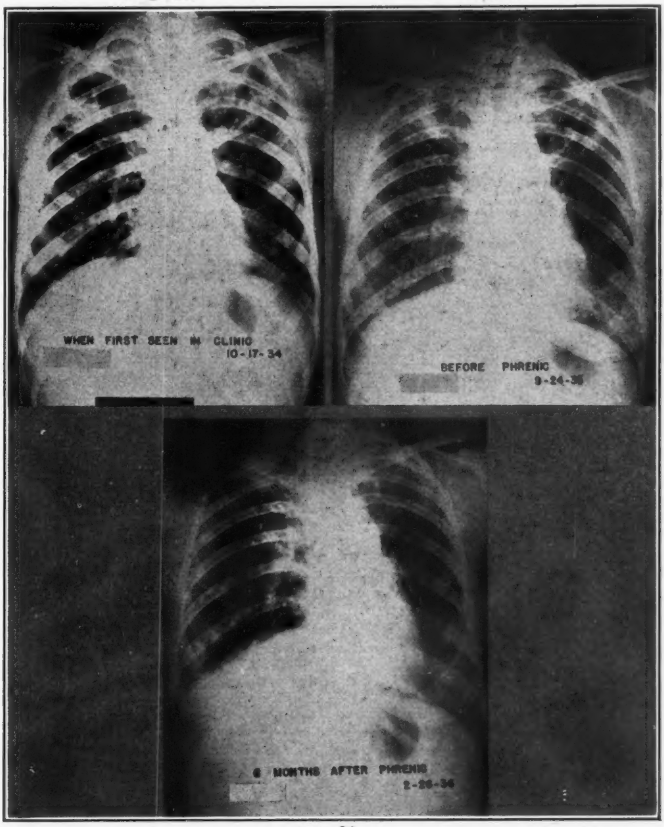

Fig. 31.

Fig. 29.—E. R., female, aged twenty-eight years, admitted November, 1934. Symptoms were anorexia, loss of weight, cough, and expectoration. Sputum positive. X-ray examination showed a bilateral mixed cavernous tuberculosis, particularly marked in the upper lobe where there was seen a large cavity. Pneumothorax was attempted first on the right then on the left, but no free pleural space could be obtained.

Fig. 30.—Same patient after eleven months of bed rest. Note moderate clearing of the infiltrate in both lungs and remarkable shrinking of the right upper lobe accompanied by reduction in size of the cavity. At that time all the symptoms except cough and expectoration subsided, patient gained weight, but the shrunken cavity in the right upper lobe had failed to show mutation for three months.

Fig. 31.—Same patient six months after temporary interruption of the right phrenic nerve. Note complete closure of the cavity and further shrinking of the upper lobe. Patient is about to undergo thoracoplasty for the left side.

TABLE IV

RESULTS IN 9 PATIENTS SUBJECTED TO THORACOPLASTY AFTER PHRENIC INTERRUPTION WAS INEFFECTIVE

CAVITY CLOSED	DEAD	CAVITY PARTLY CLOSED
5	1	3

obtained in those exhibiting little or no rise." Slavin,[12] in discussing phrenic interruption as a supplementary procedure to pneumothorax, says, "Elevation of the paralyzed diaphragm apparently plays no part in the obliteration of cavity. The latter closes in the same manner whether the diaphragm is raised, unchanged or lowered. Left-sided cavities close equally well, though the left diaphragm seldom rises to high levels." Our own experience indicates that more cavities closed when there was a moderate or marked rise in the affected diaphragm following operation. Table V shows that closure occurred in about

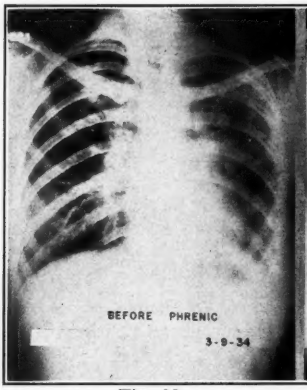

Fig. 32.

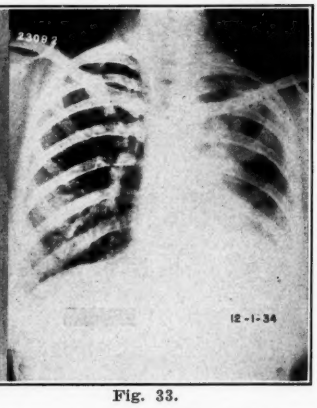

Fig. 33.

Fig. 32.—M. W., female, aged twenty-two years, admitted March, 1934, complaining of loss of weight, anorexia, cough, and expectoration. Sputum positive and mild fever. X-ray examination showed a productive cavernous process of the upper half of the left lung field and a tubulous cavity situated in the first interspace in the midzone. There was some pleural thickening over the lower lobe. Right lung showed accentuation of the pulmonary markings and discrete fine minute nodules. Pneumothorax was attempted on the left, but no free pleural space was obtained. After several months of bed rest phrenic interruption was recommended.

Fig. 33.—Same patient about nine months after temporary interruption of the left phrenic nerve. Note reduction in the size of the cavity. Clinical improvement was marked by gain in weight, loss of fever, and reduction in cough and expectoration. Patient finally came to thoracoplasty, which resulted in closure of the cavity.

25 per cent of the cases in which a moderate or marked rise in the diaphragm followed phrenic interruption as against 4.5 per cent in the group in which slight or no rise occurred.

TABLE V

RELATION OF ELEVATION OF DIAPHRAGM FOLLOWING PHRENIC INTERRUPTION TO RESULTS IN 68 CASES

SLIGHT TO NO RISE		ONE INTERSPACE RISE		TWO INTERSPACES RISE	
UNCLOSED	CLOSED	UNCLOSED	CLOSED	UNCLOSED	CLOSED
13	3	30	14	5	3

Another question which has been raised by Coryllos[6] is how long one should wait after phrenic interruption for the closure of a cavity. He seems to think that the interval that follows between operation and expected closure of the cavity, especially if long, as indicated by Nehil and Alexander,[11] is a dangerous period for some patients inasmuch as the optimum time for a more effective surgical measure is lost. From Table VI it will be seen that the average closure period was about eight months. But this is not all. Our experience has been that in those cases in which obliteration of cavity occurs, evidence of ensuing favorable results reveals itself early by unmistakable reduction in the size of the cavity. In addition we have not encountered a single case in which the tide was turned against thoracoplasty while awaiting closure of the cavity following diaphragmatic paralysis, though it must be admitted that, in a few, the plastic procedure had to be more extensive because of enlargement of the cavity following phrenic operation.

TABLE VI

INTERVAL BETWEEN OPERATION AND CLOSURE OF CAVITY IN 20 EFFECTIVE PHRENEMPHRAXES

LESS THAN 3 MONTHS	3 TO 5 MONTHS	6 TO 9 MONTHS	9 MONTHS TO 1 YEAR	OVER 1 YEAR
0	8	7	3	2

In regard to the location of the lesion and its response to paralysis of the diaphragm, Lambert[9] believes, "Whether the lesion is situated in the upper, middle or lower portions of the thorax does not appear to influence the prognosis." In the series of cases herein reported, the cavity was in the lower lobe in only three, two of which closed. We thought it might be of interest to study the location of the lesion with regard to the anterior or posterior surfaces of the lobe. Table VII is self-explanatory and proves that a knowledge of the site of the tuberculous process adds little, if any, to prognosis.

TABLE VII

LOCATION OF CAVITY WITH REGARD TO SURFACE OF THE LUNG AS DETECTED BY PHYSICAL SIGNS

UNCLOSED CASES			CLOSED CASES		
ANTERIOR	ANTERO-POSTERIOR	POSTERIOR	ANTERIOR	ANTERO-POSTERIOR	POSTERIOR
6	25	17	4	5	11

The third question that has been discussed more or less extensively in recent papers refers to the type of operation. Up to this point we have used the general term "phrenic interruption" without referring to its permanency. As shown in Table VIII about 42 per cent of the operations on the phrenic nerve were of the temporary type. In fact, all our operations in the past three years have been of this type.

TABLE VIII

TYPES OF PHRENIC NERVE OPERATION IN 95 CASES

PERMANENT		TEMPORARY	
RIGHT SIDE	LEFT SIDE	RIGHT SIDE	LEFT SIDE
21	22	23	30

Total of 96 due to the fact that one patient received an alternating bilateral temporary interruption. Briefly stated the operation consisted of the usual supraclavicular incision. After locating the main trunk of the nerve it was sectioned, and the cut ends were united by black silk suture. Any accessory branches within easy reach were severed.

In Table IX there is shown the duration of paralysis of the 40 cases in which the temporary phrenic interruption was performed. It will be noted that in a few instances the paralysis lasted less than three months. In these the nerve had been crushed—a method which we have found very unreliable and have abandoned.

TABLE IX

DURATION OF DIAPHRAGMATIC PARALYSIS IN 40 TEMPORARY PHRENIC INTERRUPTIONS

LESS THAN 3 MONTHS	3 TO 6 MONTHS	6 TO 9 MONTHS	9 TO 12 MONTHS	12 TO 18 MONTHS
5	5	9	5	16

Accepted opinions, as expressed in recent literature, indicate a preference for adopting temporary interruption of the phrenic nerve as opposed to the permanent. We have asserted in a former publication[3] that since no one can foretell which case will respond, logic should dictate against permanent paralysis of the hemidiaphragm which may later interfere to a greater or less extent with the normal function of the lower lobe if that is free from disease.

The partial or complete loss of a functioning lower lobe is particularly undesirable should thoracoplasty at a later date be found necessary for a lesion in the upper lobe which had failed to respond satisfactorily to phrenic interruption. Under such circumstances, especially in the presence of a fibrotic process in the better lung, the patient may suffer from respiratory embarrassment due to the reduced respiratory capacity caused by the paralysis. Should the sound lung break down and collapse therapy be required, a permanently paralyzed diaphragm may be a tremendous handicap as is illustrated in the following case:

F. L., male, aged twenty-eight years, admitted February, 1933. Present illness dates back to June, 1930, when he had several episodes of streaking followed by small hemorrhages. After visiting the clinic a diagnosis of mixed cavernous tuberculosis of the right lung was made, and his admission to the state sanatorium

was arranged. He remained in the sanatorium for nine months and upon discharge continued to be observed in the clinic. Because of return of symptoms a right-sided pneumothorax was attempted, but no free pleural space was found. Phrenicectomy was performed in November, 1932, but it did not affect the cavity. In February, 1933, a partial thoracoplasty confined to the right upper lobe was done, and, except for change in shape, the cavity was not materially reduced in size. Clinically he made a good subsequent improvement and finally signed a release to continue treatment at home.

In the latter part of 1934 the patient was readmitted because of loss of weight and increase in cough and expectoration. At this time an x-ray examination revealed

Fig. 34. Fig. 35.

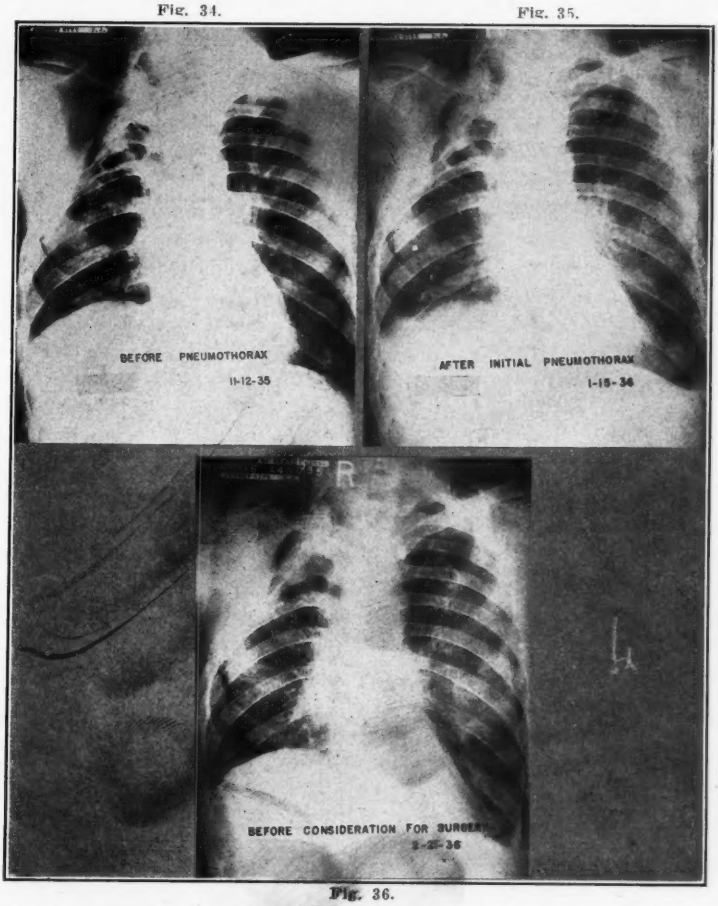

Fig. 36.

Fig. 34.—F. L., male, aged twenty-five years, admitted February, 1933. This x-ray film shows condition of the patient after a right-sided phrenicectomy and a partial thoracoplasty and just before pneumothorax on the left side for the upper lobe cavity beneath the first rib and extending into the first interspace in the midzone.

Fig. 35.—Same patient after pneumothorax had been carried to its maximum extent in the presence of dyspnea and when the patient was considered for pneumolysis. The operation, however, was not performed because of the dyspnea, which was thought to be caused by the paradoxical motion of the right diaphragm.

Fig. 36.—Same patient after partial collapse of the left lung, which is held out by adhesions to the apex. Note cavity in the first interspace.

a small cavity in the apex of the left lung. After a short period of bed rest pneumothorax was induced because of no change in the cavity. The pneumothorax which has been continued for several months cannot be carried beyond a very partial type because of dyspnea, and it is ineffective because of apical adhesions. While pneumonolysis is indicated, it is not advisable because of the dyspnea which is believed to be due to the paradoxical motion of the permanently paralyzed right hemidiaphragm (see Figs. 34, 35, and 36).

This idea is clearly brought out by Nehil and Alexander[11] in the following statement: "We have repeatedly seen patients with bilateral tuberculosis in whom was demonstrated the tragedy of a permanent paralysis having been produced. The operation may have brought about arrest of the lesion in the lung of the operated side but what reduction in total respiratory function the paralysis caused has not rarely prevented our performing some effective operation on the opposite side for lesions that may later have progressed there."

Another argument against permanent paralysis of the diaphragm is inferred from the work of Carlson, Ballon and Graham.[13] These investigators have shown experimentally that cough and expectoration may be interfered with following phrenic interruption. Clinically such instances have been encountered, as cited above, with resulting fulminating tuberculous bronchopneumonia due to internal drainage.

Finally Lambert[9] calls attention to an objection which we have encountered on three occasions when we, too, regretted having a permanently paralyzed diaphragm. He states, "We have found that the rise of the diaphragm with the consequent rise of the intraabdominal organs has been a real obstacle in effecting a satisfactory collapse of the lower and middle regions of the lung in the subsequent and later stages of thoracoplasty because the abdominal pressure tends to hold outward the chest wall from which the lower ribs have been removed. We also believe that an active diaphragm by its inherent muscular tonus and contraction will pull inward the anterior ends of the resected lower ribs and will also aid the action of gravity in drawing inward the upper chest wall after the removal of its support of the upper ribs by maintaining a constant downward traction on the pulmonary tissue and thus will aid collapse."

It must not be overlooked, however, that a temporary interruption of the phrenic nerve carries with it certain undesirable features:

First, postoperative care of the patient must include frequent fluoroscopic observations so that paralysis of the diaphragm may be reestablished if it is lost prematurely. Should this not be done, cavities almost obliterated may enlarge again or if fully closed reopen with resumption of motion of the diaphragm. As mentioned above, in the case of two of our patients in whom closure of cavity was obtained, the lesion recurred because a prematurely lost paralysis was not reestablished. In a few others, the cavity, almost fully obliterated, enlarged again for the same reason (Figs. 37-43).

Second, reoperation is not so simple an effort in every instance as mere mention of the word. It has been our experience that a second attempt to find the phrenic nerve is fraught with many difficulties because of the displacement from its normal course by the scar tissue in the soft tissues about the nerve. Reoperation at times taxes the patient's energies to a greater extent than in the original one, and does not always assure him success.

Fig. 37. Fig. 38.

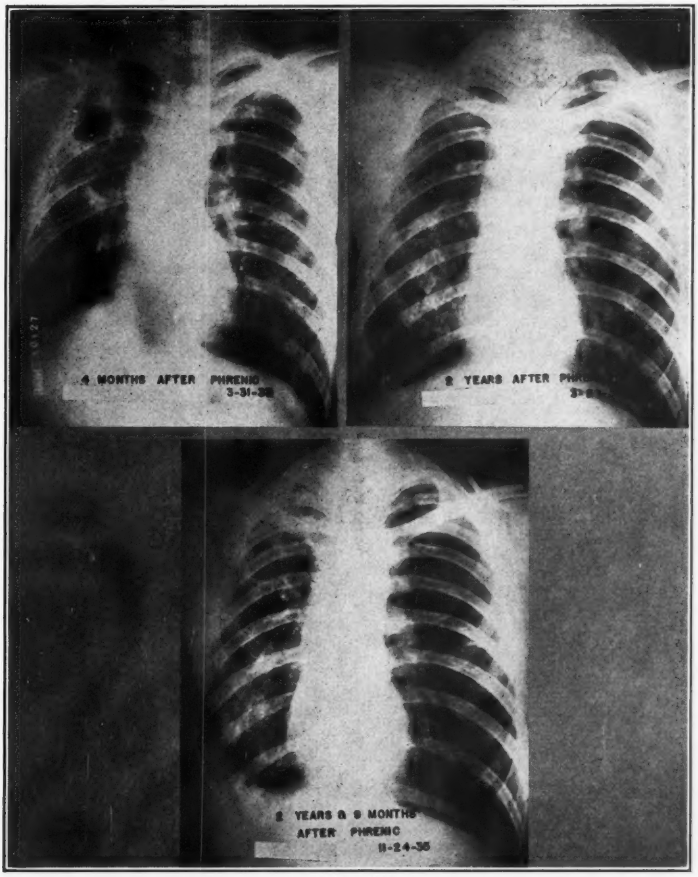

Fig. 39.

Fig. 37.—J. C., male, aged eighteen years, admitted July, 1932, complaining of loss of weight, cough, and expectoration. Sputum positive. Pneumothorax was attempted but failed because of adhesions. After several months of bed rest a temporary interruption of the right phrenic nerve was induced. This x-ray film shows the process in the right lung four months after phrenic interruption, and this was essentially the condition before the operation. Note the moderate-sized cavity in the first interspace surrounded by mottled infiltrate. There is also seen a triangular shadow along the cardiac margin due to an accessory lobe.

Fig. 38.—Same patient two years after phrenic interruption. Cavity had been closed for several months, but at that time the diaphragm had descended to its normal position and was freely mobile. Reinterruption of the nerve was not induced.

Fig. 39.—Same patient nine months later showing recurrence of the cavity, pleural effusion, and return of symptoms including positive sputum.

PHRENIC INTERRUPTION SUPPLEMENTARY TO AN INEFFECTIVE PNEUMOTHORAX

Before considering the value of adding an induced paralysis of the diaphragm in order to turn an unsatisfactory pneumothorax effective, we should like to stress that, since pneumonolysis is the most direct method by which offending adhesions can be interrupted, supplementary phrenic operation should be considered only in the presence of

Fig. 40. Fig. 41.

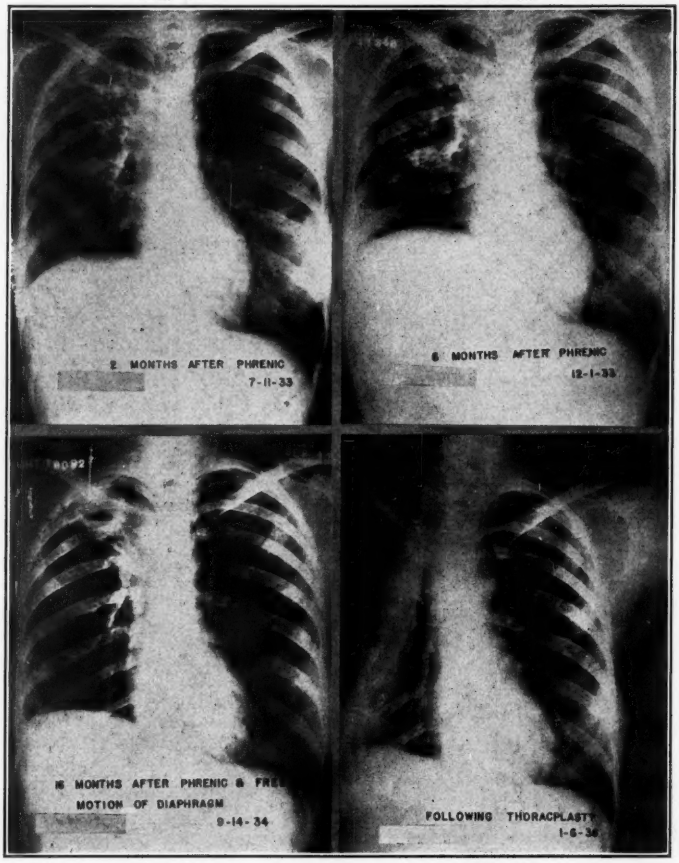

Fig. 42. Fig. 43.

Fig. 40.—L. M., female, aged twenty-nine years, admitted May, 1933, with symptoms of cough and expectoration. Sputum positive. X-ray examination showed a productive cavernous infiltrate in the upper half of the right lung. Pneumothorax was attempted, but no free pleural space could be found.

Fig. 41.—Same patient six months after temporary phrenic interruption on the right. Note almost complete obliteration of the cavity.

Fig. 42.—Same patient sixteen months after phrenicectomy. Diaphragm had been freely mobile for several months. Note reopening of the former cavity.

Fig. 43.—Same patient, showing complete obliteration of the cavity following thoracoplasty.

obviously nonseverable adhesions or after diagnostic thoracoscopy convinces the operator of the inadvisability of cauterization. In all other respects the principles enumerated in the discussion of the temporary versus permanent interruption hold true here.

As far as indications are concerned, we should like to stress that satisfactory results are obtained most frequently in those cases in which the partly collapsed lung is suspended to the apex and the diaphragm. It matters little whether the adhesions to the diaphragm are strings, cords or folds or even if the entire base of the lung is adherent, provided the diaphragm is freely mobile. The suspension of the upper part of the lung, however, should be by adhesions which have the capacity to relax under the influence of a paralyzed diaphragm. Strings and cords or bands are of the preferable type; folds

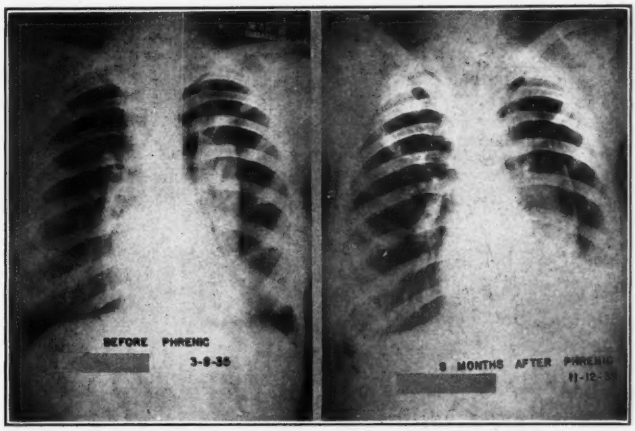

Fig. 44. Fig. 45.

Fig. 44.—J. H., female, aged seventeen years, admitted February, 1935, presenting all the classical symptoms of pulmonary tuberculosis. Pneumothorax was immediately induced on the left side, and as seen in the x-ray film the partly collapsed lung was suspended to the apical pleura and attached to the diaphragm. A residual cavity is seen in the first interspace.

Fig. 45.—Same patient eight months after temporary interruption of the left phrenic nerve. Note good elevation of the diaphragm and complete obliteration of the cavity, although collapse of the lung is much less.

less so, while apical caps entirely contraindicate a supplementary phrenic operation. Laterally radiating adhesions, on the whole, respond satisfactorily much less frequently. A study of Table X will reveal that closure of the cavity was obtained in 50 per cent of the cases. More interesting, however, is the fact that two-thirds of the closures occurred in those patients whose partly collapsed lung was suspended both to the apex and the diaphragm. We believe, therefore, that these are the most appropriate cases for phrenic interruption supplementary to pneumothorax (Figs. 44-48).

The remainder of the cases in the study comprise a group for which diaphragmatic paralysis was induced for various purposes generally recognized, and require no further discussion. See Table XI.

CONCLUSIONS

In conclusion we should like to stress, as indicated above, that phrenic interruption as an independent procedure has a definite place

Fig. 46. Fig. 47.

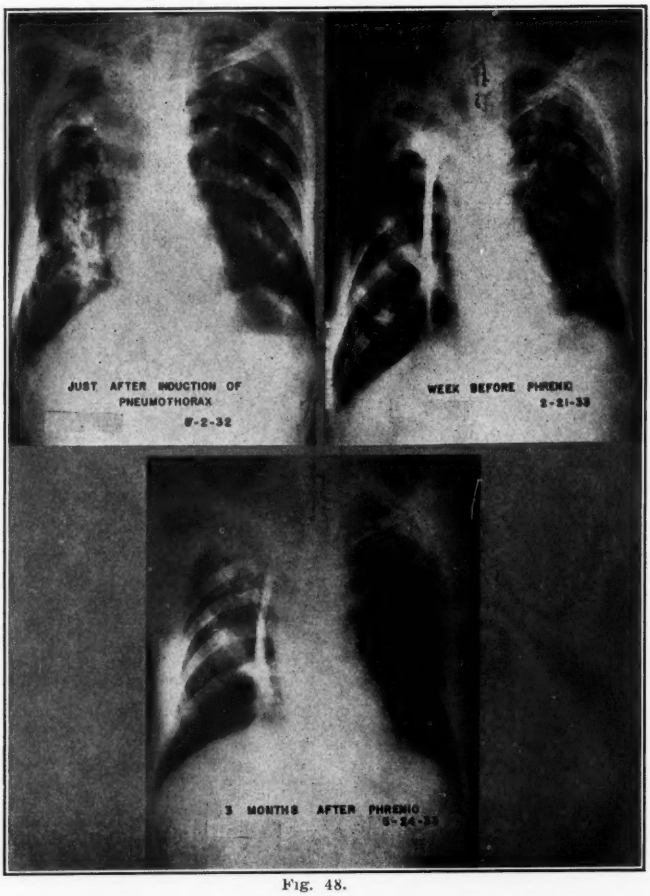

Fig. 48.

Fig. 46.—S. C., male, aged fifty-nine years, admitted July, 1932, complaining of loss of weight, anorexia, cough, and expectoration. Sputum positive and moderate fever. The x-ray film shows condition just after the induction of pneumothorax. Note the extensive mixed cavernous infiltrate of the entire right lung, the upper lobe of which is partly shrunken and contains a large cavity. There are also scattered dense minute foci in the left lung.

Fig. 47.—Same patient six months after induction of pneumothorax. Note complete collapse of the middle and lower lobes and reduction in size of the cavity in the upper lobe. The lung is suspended to the diaphragm.

Fig. 48.—Same patient three months after permanent interruption of the right phrenic nerve. Note complete obliteration of the cavity in the upper lobe. The sputum at that time was negative.

TABLE X

TYPES OF ADHESIONS ENCOUNTERED IN 12 PATIENTS SUBJECTED TO PHRENIC INTERRUPTION SUPPLEMENTARY TO INDUCED PNEUMOTHORAX

NO.	DESCRIPTION OF LESION	RESULT
1.	Partial pneumothorax left, the upper lobe of the lung contains a moderate sized cavity which is kept patent by folds of pleura radiating to the apex and axilla.	Effective
2.	Partial collapse of the left lung which is adherent by its base to the diaphragm. Its upper lobe in which there is seen a cavity is suspended to the apical pleura by cord adhesions.	Effective
3.	Bilateral upper lobe cavernous lesion and partial collapse of the left lung which is held out in the region of the first and second intercostal spaces by folds of pleura.	Ineffective
4.	The left upper lobe is completely collapsed and suspended to the apical pleura by string adhesions. The lower lobe only partially collapsed is held out laterally by folds. Cavity present.	Ineffective
5.	Hydropneumothorax with a small quantity of fluid in the costophrenic sinus on the left side. The lung is held out to the apex and diaphragm by bands of adhesions. Cavity visible in the upper lobe.	Effective
6.	Fibrocavernous process in right lung which is partly collapsed but ineffectively due to fold adhesions radiating from the upper lobe to the apical pleura.	Effective
7.	Partial right-sided pneumothorax and partial collapse of the upper lobe within which there is an apical cavity suspended by an apical cap.	Ineffective
8.	Partial collapse of the left lung which is adherent to the diaphragm and suspended to the apical pleura by a broad band. Cavity present.	Effective
9.	Bilateral exudative cavernous tuberculosis and a partial collapse of the right lung which is suspended to the apical pleura. A large cavity in the upper lobe is held open.	Ineffective
10.	Partial pneumothorax on the left and a cavity in the upper lobe which is suspended by a cord adhesion radiating to the apical pleura. Mixed cavernous lesion in the right lung.	Ineffective
11.	Partial collapse of the left lung in which there is a large thick-walled cavity held out to the axillary pleura by folds. The pericavernous infiltrate is of the caseous bronchopneumonic type. A similar infiltrate is seen scattered throughout the right lower lobe.	Ineffective
12.	The right lower lobe is completely collapsed and adherent to the diaphragm by a long cord. The upper lobe is diffusely attached to the parietal pleura, and contains a cavity.	Effective

in the treatment of cavernous tuberculosis. If the cases are selected in accordance with the indications given, one may expect closure of the cavity in a very appreciable number and clinical improvement, with or without reduction in size of the cavity, in a small group for which thoracoplasty is made possible. While it is true that more advanced disease can be managed successfully only by pneumothorax or thoracoplasty, nevertheless one should not lose sight of the fact that the lesions which respond favorably to induced diaphragmatic paralysis are found in individuals in whom pneumothorax was impossible or had failed and thoracoplasty either contraindicated or if suitable, may not infrequently be spared.

TABLE XI

NO. OF CASES	PURPOSE OF PHRENIC NERVE OPERATION	NO. OF EFFECTIVE RESULTS
5	For reduction of intrapleural space due to incomplete reinflation of lung following artificial pneumothorax.	4
4	Supplementary to pneumothorax to prolong refill intervals by reducing intrapleural space.	4
2	Supplementary to thoracoplasty for closure of incompletely closed cavity.	1
2*	As a test for better lung prior to thoracoplasty.	
2	To supplement pneumothorax prematurely lost.	

*We no longer consider this an indication, for one has no assurance that the better lung will have the capacity to stand up under the additional relaxation of the worse side by thoracoplasty.

The operation as a supplement to an ineffective pneumothorax should be utilized only when pneumonolysis is obviously contraindicated or inadvisable following thoracoscopy, and for adhesions of the nature described, and particularly when they suspend the partly collapsed lung to the apex and diaphragm. With extensive adhesions it is far better either to abandon the pneumothorax for or to supplement it with a thoracoplasty.

Aside from these two uses the procedure serves a very limited purpose in a selective group for numerous reasons but especially for the reduction of the intrapleural space to compensate for reduced lung volume following cessation of pneumothorax.

SUMMARY

1. The report includes 95 cases in which phrenic interruption was performed and which were followed from one to five years postoperatively.

2. Of the 95 cases, the operation was used as an independent procedure in 68, as a supplement to ineffective pneumothorax in 12, and for miscellaneous reasons in 15.

3. The contraindications and the indications for diaphragmatic paralysis are described in detail.

4. Of the 68 cases in which the operation was used independently, 38 were found suitable in retrospect. Of the suitable group, closure of cavity occurred in 47 per cent, reduction in size of cavity with general clinical improvement in 31 per cent, and thoracoplasty spared in 15 per cent.

5. The average interval between operation and closure of cavity was seven and one-half months.

6. The average period of observation of the closed cavity group has been three years.

7. Temporary interruption is advocated for reasons presented.

8. In no failure case was the opportunity for thoracoplasty lost while awaiting closure of the cavity following diaphragmatic paralysis.

9. The operation, when used as a supplement for ineffective pneumothorax in selected cases, where there is a bow string effect, offers about 50 per cent success.

10. The reduction of the intrapleural space is the chief indication for the miscellaneous uses of phrenic interruption.

We wish to acknowledge our indebtedness to Dr. George V. O'Hanlon, Medical Director of the Jersey City Medical Center, for the privilege of operating and the service of the operating room personnel.

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DIFFICULTIES OF THORACOPLASTY AND UNCOLLAPSIBLE CAVITIES

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A LARGE number of papers have been written about the satisfactory results of extrapleural thoracoplasty. The gradually developing changes in the technic of the operation have been fully described, and many sets of statistics have been offered giving the percentage of patients clinically cured with cavities completely closed and sputum either absent or bacillus free. It is not proposed here to offer more statistics along these lines but to consider those cases in which the cavity remains open in spite of several carefully planned stages of thoracoplasty. The actual percentage of such failures as regards cavity closure varies greatly in different clinics and will undoubtedly continue to do so. If the surgeon is fortunate enough to be given early cases upon which to operate, those in which cavities are new and relatively small and not yet surrounded by dense fibrous walls, the number of completely satisfactory results is sure to be high. If he has to operate upon old chronic cases with firm walled cavities, the percentage of closures will certainly be much lower.

It has been my discouraging experience during the last year or two to find a majority of this latter type of case among those coming to operation. This fact should not, in any way, be taken as a reflection upon the phthisiologists who have referred the cases for surgery. They are constantly referring earlier cases for operation in accordance with the accepted thought of the present day. But it seems that recently a crop of old cases has come up, some arriving in Saranac Lake and the surrounding sanatoriums with lesions already far advanced, others returning here after long absences elsewhere, and others finally consenting to operation after having refused it during previous years. There has also been a group of patients who were operated upon several years ago before the technic had been changed to include full length resection of the top ribs and removal of the transverse processes. These have requested reoperation for the incompletely closed cavities.

Concerning the complete success achieved in the favorable cases nothing will be said. It is the unsuccessful ones that I wish to consider.

What are the factors contributing to failure? Faults in the operative technic? Or the character of the lung itself?

After careful consideration it seems that in the great majority of cases the latter is the real cause. The few cases in which failure probably can

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be blamed with justice on faulty technic are those in which there are unduly long delays between stages. These delays arise from wound infections, and from pulmonary or cardiac complications. It is almost always impossible to place the blame in wound infections. In the midst of a series of perfectly clean wounds one will suddenly become septic. It is an unfortunate accident. Pulmonary complications, while very unusual, do occasionally occur and are unavoidable. By the use of careful judgment in the choice of cases and in the amount of work done at one stage, cardiac complications are also infrequent, but here again they are bound to occur occasionally. If a delay of several weeks is necessary, the surgeon is faced with a very difficult problem as to how to proceed at the next stage. If the regular operation is done, simply removing ribs from where the previous stage left off, the collapse is almost sure to be unsatisfactory because of hardening of the periosteum above. If an attempt is made to remove the reformed bone over the site of the previous stage or stages, this is enough of an operation in itself to make it risky to go ahead and take out the new ribs. If the new ribs are not taken out, it means a whole stage done without any real progress being made toward completion of the operation, and the extra time in the hospital and nursing and operating room expense may be of great importance to the patient, especially when he has figured up the probable total amount necessary to see him through and has just been able to raise that much.

In the cases which go through on schedule, that is, two to two and one-half weeks between operations, the technic which I think is pretty well standardized throughout the country has been used. In almost all patients with upper lobe cavities the first stage consists in removal of the top three ribs, taking practically the entire length of the first and second and a long piece but not all of the third. There is a difference of opinion about removal of the transverse processes of these three. Since I have never seen an x-ray film following a first stage in which the cavity, regardless of its original position, has not retreated well below the fourth rib, it does not seem necessary to remove the first three processes. Frequently the process of the third is removed, however, just to be on the safe side. This lack of removal of the first two may come in for severe criticism in some quarters. I am still to be convinced of its desirability.

As an addition to the first stage, in nearly all cases during the past year, the extrafascial apicolysis of Carl Semb[1] has been done. The technic of this maneuver is really very simple and adds little to the time or shock of the operation. By careful blunt dissection, cutting only when absolutely necessary, and then between clamps if there is any possibility of there being a vessel in the band being cut, the whole apex of the lung is freed from its surrounding structures. Then, if the lung is soft, it drops down to the level of the fourth rib. One of my associates, Dr. S. A. Wolfson, has suggested an addition to the technic at this point,

which in the last few weeks has been used wherever possible. This consists in suturing the apex of the lung down in this collapsed position. Several strands of chromic catgut are run across from the anterior stumps of the ribs to any firm tissue along the spine at the level of the fourth rib. In passing across the dome of the thorax these strands are caught through the parietal pleura in several places. When these sutures are tightly tied, the lung is securely held down. It is a little difficult at times to find suitable places in which to attach the sutures in the front and back of the chest, but this can be accomplished with a little patience.

When the lung is hard and fibrous, however, it stands up in the top of the thoracic cavity, even after a fairly complete Semb apicolysis. It feels firm in the hand and cannot be pushed down to the fourth rib even

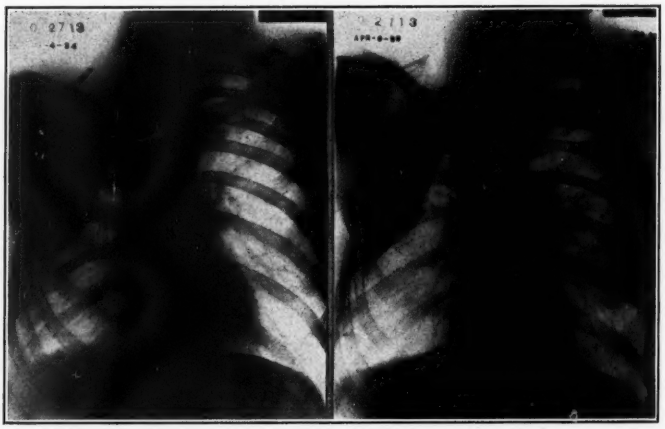


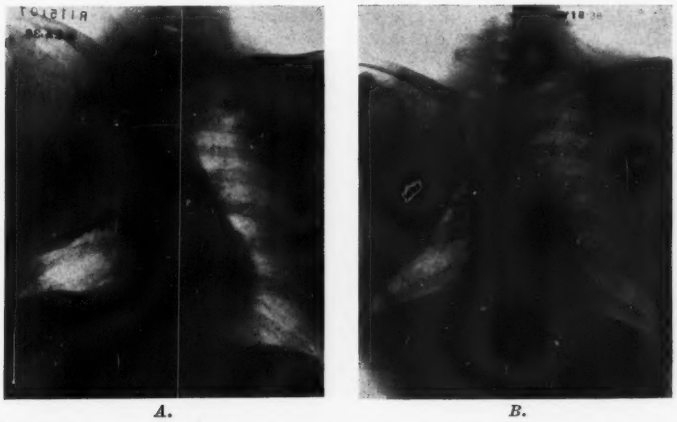
Fig. 1.—The first view shows an apparently completely satisfactory result shortly after the completion of a thoracoplasty. The second film taken two years later shows the presence of a long narrow cavity close to the spine in the operated region. This is typical of many cases which could easily be reported as completely satisfactory soon after operation but later proved to have cavities still open.

with considerable force. The above mentioned maneuver of Wolfson then seems impossible or futile. It is in cases of this type that one learns to expect disappointing results. One goes on and does the second and if necessary third or fourth stages, even removing the anterior portions of the ribs through the axillary operation—but the ultimate x-ray picture still shows a partly open cavity. It is usually very markedly reduced in size. It may be only a long narrow slit or a triangle lying close to the vertebral gutter, and it may be only one-tenth of its former size—but it is still open and there is probably still positive sputum.

It is very easy to be deceived into a false sense of satisfaction by the first x-ray pictures which are taken shortly after completion of a thoracoplasty. If the films are taken by the ordinary technic, cavities

frequently appear to be obliterated only to show themselves as open again in films taken two or three months later. This is especially true if the subsequent films are taken with a Bucky diaphragm or are deliberately overexposed. After seeing many examples of this, one cannot help wonder whether some of the reports of very high percentages of complete closure are not based upon early x-ray pictures—that is, those taken immediately after the conclusion of the operations.

What is to be done in these unsuccessful cases? Should one reoperate in a second attempt to secure complete cavity collapse? Carl Semb,[1] who reports 90 per cent of cavity closures by his original operation of thoracoplasty plus extrafascial apicolysis, also reports complete collapse of cavity in eleven out of fourteen reoperations attempted. In the past nine months I have done reoperations on six cases, all originally operated upon several years ago. The removal of the bone is much easier if one



A. *B.*

Fig. 2.—Two x-ray films, one taken one week following thoracoplasty, the other three weeks later. The first one shows no definite evidence of cavity, the second one taken with special technic shows the presence of a long cigar-shaped cavity close to the spinal column in the collapsed area. Postoperative results reporting complete closure of cavities following operation are frequently based on pictures like the first one of these two.

begins anteriorly and works backward toward the spine, especially if there is some small remaining portion of normal rib in front to start on. If the patient has already had an anterior operation, the task becomes much more difficult. But even under the most favorable conditions the removal of the reformed deformed bone plates is time consuming. Transverse processes are of course removed if they have not been taken previously. Semb states that after removal of the bone he goes on and does an apicolysis, although granting that this is much more difficult than in original cases. I find that anything approaching complete apicolysis is impossible. In the six cases attempted all six cavities have been reduced in size but *not one has been closed.* Positive sputum before re-

operation has continued positive afterward. One of the cases, originally operated upon three years previously, presented the heaviest bone plates I have ever seen. Nearly two hours of hard work resulted in a window in the bone overlying the upper lobe about 4 inches by 3 inches and a partial freeing of the lung from the vertebral column and at the top. The recovery of the patient was slow, and a wait of six weeks was necessary before another stage could be done. At this operation very little more bone was removed, but a very painstaking attempt was made to free the lung anteriorly from its bony attachments. Suddenly the cavity was broken into. Its roof was found to be only a layer consisting of the two pleuras no thicker than ordinary blotting paper. Since closure of the hole into the cavity was out of the question, it was opened widely and drained. The result was a stormy convalescence with complete wound

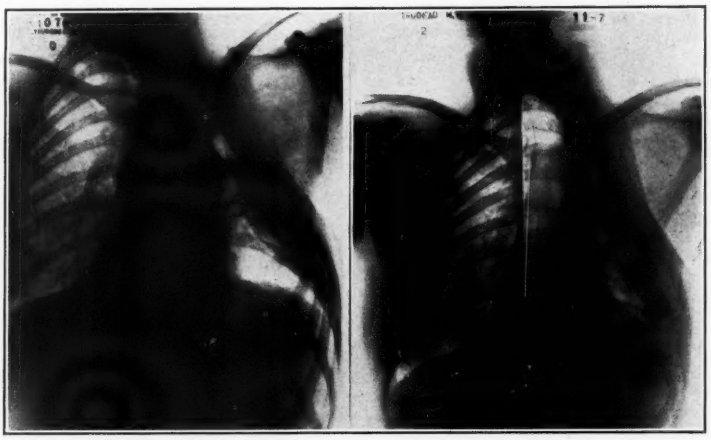


Fig. 3.—The picture on the left shows a long cigar-shaped cavity remaining after thoracoplasty done two years previously. The picture on the right shows the same case after reoperation. With ordinary x-ray technic it might easily show complete closure. The cavity is still present, however, practically the same size, but pushed over until it lies in front of the spinal column. This case is typical of the reoperations mentioned in this paper.

infection. One month later the patient developed tuberculous meningitis and died. This was the only one of the six cases in which anything untoward happened, the others all recovering as promptly as ordinary thoracoplasties. In one case done several years ago this same accident of breaking into the cavity occurred. This patient eventually recovered after a long period of high fever, but when last seen two years later she still had an annoying fistula in her back.

Is the chance of obtaining a completely satisfactory result worth the ordeal of the reoperation plus the risks incurred? Is it worth while to go through this for the undoubted possibility of complete closure, but greater probability of merely having the cavity reduced in size? Based on my personal experience, rather than on published statistics, I am

inclined to doubt it. Recently a number of old patients have come to me asking for reoperation. They are all pretty well, able to be out and around and enjoy life, but they still have partly open cavities, and raise small to moderate amounts of sputum containing bacilli. Their disease has not apparently advanced since their thoracoplasties two or three to six or seven years ago. I have advised them to let well enough alone and not to be reoperated upon.

I also have patients who have had their original operations done within the last two years, with the modern technic. Their top stages have been extensive. Their transverse processes have been removed. They have had apicolysis. Some have had anterior operations, and still their cavities are seen to be open if the proper x-ray technic is used. What can one hope to accomplish in these cases by reoperation? If all possible bone is removed originally and the cavity fails to collapse, why should it collapse any further at reoperation? I believe we must face the fact that some cavities, due to the inherent quality of their walls and the surrounding lung tissue, will not collapse competely, and not overdo our efforts to bring about total closure.

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THORACOSCOPIC REMOVAL OF BROKEN ASPIRATING NEEDLE

Case Report*

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BREAKING the needle while aspirating the chest or giving pneumothorax is an accident alarming to the patient and annoying to the operator. In spite of all precautions it occurs occasionally in any institution in which a large amount of chest work is carried on.

In the three sanatoriums of the Saskatchewan Anti-Tuberculosis League from 1917 to the end of 1935, there were performed approximately 59,680 chest punctures: 54,960 for pneumothorax, 4,720 for aspiration. With this there were six broken needles: three with pneumothorax, and three during aspiration.

The break usually occurs deep in the chest wall at or near the intercostal fascia, and removing the retained portion is often difficult. Even with the aid of the fluoroscope it may be a time-consuming procedure to locate the piece, while the long incision and wide exploration often necessary are undesirable, to say the least. Any one who has attempted this task is cognizant of the difficulties.

In the case reported here a method was used which was simple and so far as we know has not been used before.

The patient had had a long standing compression oleothorax with almost complete collapse of the lung, but the sputum had become positive again. The oil had been removed to facilitate study of the case with a thoracoplasty in view. A small amount of sterile cloudy fluid had collected in the pleural space and was being aspirated at intervals. This was fairly difficult on account of the greatly thickened pleura. It was while one of these aspirations was being done by a member of our staff that the needle, a two-inch No. 18, snapped after the pleural space had been entered. It had been inserted in the sixth intercostal space in the midaxillary line.

The end of the fragment could not be palpated, so a long incision was made and the area explored down to the ribs, but without result. Efforts to grasp the needle or mark its location under the fluoroscope did not lead to success, and after two hours of unavailing effort the attempt was given up.

Later in the day, after viewing stereoscopic films, the patient was prepared for thoracoscopy. A Jacobeus-Unverricht right-angle vision thoracoscope was introduced through a Matson cannula in the anterior axillary line in the intercostal space above the needle. About three-fourths of an inch of the needle was plainly visible, protruding directly into the pleural space. A second cannula was inserted at the same level as the other in the posterior axillary line. The needle then

*From the Prince Albert Sanatorium of the Saskatchewan Anti-Tuberculosis League.
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appeared to be pointing more toward the anterior cannula, so the thoracoscope was transferred to the back and an intrathoracic hemostat (a urethral forceps) was introduced anteriorly.

The needle was grasped by its point at an angle of about 145 degrees to the shaft of the hemostat and easily pulled into the chest. While drawing it into the cannula it twisted out of the forceps jaws and dropped back into the pleural space. It was then seen to be lying in a position in which it could be grasped in line with the shaft of the instrument. It was readily drawn out through the cannula. The operation was completed in fifteen minutes from the insertion of the first trocar.

The procedure was so simple and the scars left were relatively so small that it almost would appear to be the method of choice in cases in which the broken needle has protruded into the pleural space and the proximal end cannot be palpated with certainty. A pleural space roomy enough to insert and manipulate the instruments is essential, of course, and a sterile empyema is not a contraindication to thoracoscopy.

A variation of this procedure which we had in mind was to push the needle outward so that it could be located through the previous incision, but this probably would have been more difficult.

Dr. A. R. McPherson of our staff suggests marking the location of the broken piece before changing the position of the patient from vertical to horizontal, lowering the arm and shoulder, or otherwise changing the relations, by inserting a second needle through the same skin opening as nearly as possible at the same angle. This should be helpful in finding the fragment by incision and exploration.

ONE-STAGE PNEUMONECTOMY UNDER LOCAL ANESTHESIA: SUCCESSFUL CASE REPORTED

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IN THE excellent report of Cameron Haight[1] on pneumonectomy published in April, 1934, were contained the items from which the following table is derived:

AUTHOR	SUCCESSFUL	UNSUCCESSFUL
Haight	1	
Nissen	1	
Sauerbruch	1	
Macewen	1?	
Kuemmell		1
Willy Meyer		3
Lillienthal		3
Archibald	1	1
Ivanissevich		1
Windsberg	1	
Graham	1	
Rienhoff	2	
Alexander	1	2
Freedlander	1	
Overholt	1	
Totals:	12	11

Subsequently, there have been 18 additional cases reported as follows:

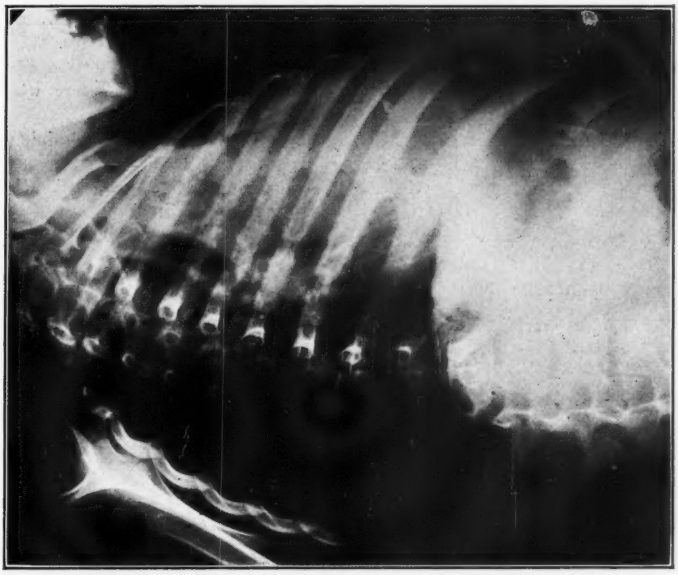
AUTHOR	SUCCESSFUL	UNSUCCESSFUL
Mason[2]	2	
Overholt[3]	4	3
Flick[4]		1
Rienhoff[5]	7	1
Totals:	13	5

This makes 41 cases in all, of which number 25 were successful and 16 unsuccessful, or a mortality of 39 per cent. This includes, however, the earlier cases in which the mortality was very high. If one considers the last 30 cases reported, there are 9 fatalities, or a mortality of 30 per cent. The objects of this paper are to report another successful case and to outline the technic and advantages of local anesthesia for this procedure.

The patient was a girl eight years of age, who one and a half years before admission began to cough and to lose appetite and weight. She became listless and showed a febrile reaction every afternoon. In some four to six weeks she began to expectorate foul-smelling pus in fairly large quantities. She was hospitalized in her home town and a diagnosis of left empyema with bronchial fistula was made. An intercostal tube was inserted and pus was drained, following which she greatly improved in every way. After a month of drainage, however, the tube was removed and she was discharged. The sinus continued to drain but, as it

*From the Surgical Department, Temple University Medical School.
Received for publication, November 11, 1936.

grew smaller, the symptoms returned. During the next six months she was again hospitalized on two occasions. No further drainage was done, but she was treated conservatively with slight improvement.



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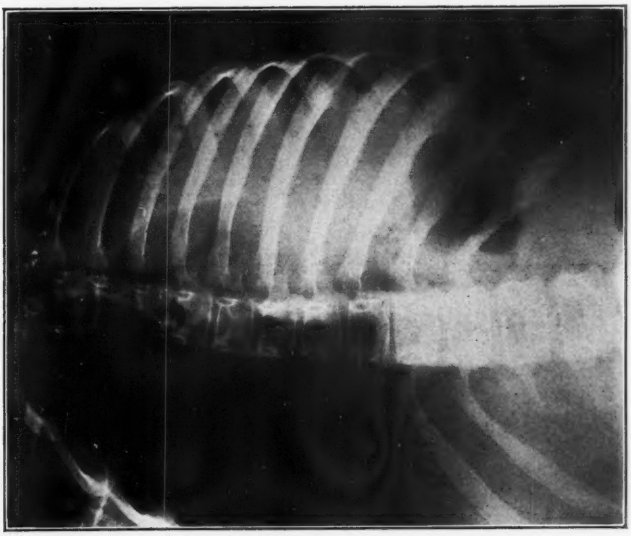


A.

Fig. 1.—On admission, diffuse opacity with multiple small radiolucent areas, suggesting bronchiectatic cavities. Mediastinal shift to left with herniation of uninvolved right lung through superior mediastinum. Spurs about draining sinuses, seventh interspace.

When admitted to Temple University Hospital in February, 1936, she was weak, pale, and had a severe cough with expectoration of some 120 to 180 c.c. daily of foul-smelling pus. Chest examination revealed consolidation of the whole left side with

great increase in breath sounds from the seventh rib upward and absence of them from that point downward, posteriorly. At the inferior angle of the left scapula, cavernous breathing, bubbling râles, and whispered pectoriloquy were present. Over the right chest, there was hyperresonance, the breath sounds were physiological, and there were no adventitious sounds. There was a persisting sinus in the left seventh interspace, filled with chronic granulations, and draining pus in small quantity. The heart was displaced to the left, its rate was 100 to 120; rhythm and heart sounds were normal, and there were no thrills or murmurs. The blood pressure was 102/70/32. Moderate clubbing of the fingers was present.

The x-ray examination (Fig. 1) revealed spurs on the ribs adjacent to the draining sinus and diffuse opacity of the entire left hemithorax, punctuated by numerous small radiolucent areas, suggesting bronchiectasis or multiple abscess, although empyema could not be entirely ruled out. Mediastinal hernia of the right lung was also depicted from the third to the seventh ribs, posteriorly. The right lung showed no involvement.

The hemogram was:

Hemoglobin—11.5 gm.
Red blood cells—4,800,000
Leucocytes—14,000
Polymorphonuclear neutrophiles—65%, of which 35 were nonfilament forms
Lymphocytes—25%
Monocytes—5%
Eosinophiles—2%
Basophiles—1%

The urinalysis was negative. Wassermann and Kline reactions were negative. Kahn reaction was a doubtful positive.

Bronchoscopic examination revealed a tremendous amount of purulent secretion in the trachea and left bronchus. No evidence of obstruction could be seen. Several large masses of necrotic tissue were coughed up through the bronchoscope. These were followed by rather free bleeding. Secretions from the bronchi revealed no tubercle bacilli, spirochetes, or mycoses. Culture produced micrococcus catarrhalis, nonhemolytic streptococcus, nonhemolytic staphylococcus, and an occasional hemolytic streptococcus on both aerobic and anaerobic culture.

The electrocardiographic studies were normal except for slight right axis deviation.

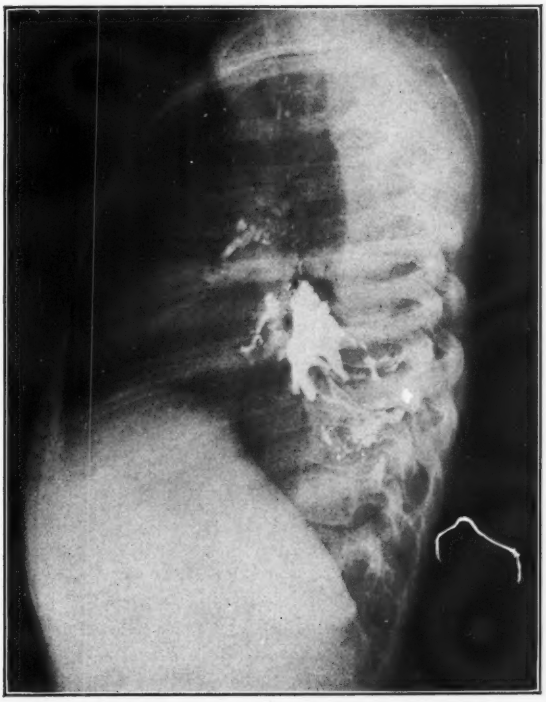
Three days after admission, portions of the seventh and eighth ribs were resected about the sinus tract and this was opened widely, revealing a large cavity in the pulmonary tissue, apparently extending well above the hilus. This produced decreased cough and expectoration and considerable general improvement. Ten days later, lipiodol mapping revealed the large cavity communicating with both upper and lower lobe bronchi (Fig. 2).

Two weeks after rib resection, one-stage pneumonectomy was done under local and field block anesthesia. Preliminary medication consisted of morphine sulphate, gr. 1/12, one and a half hours before and gr. 1/8 one-half hour before operation. No inhalation anesthesia was utilized and no positive pressure was needed because of the complete consolidation of the left lung.

The specimen (Fig. 3) was a completely carnified lung. The only aerated portion was a small strip along the costophrenic sulcus, estimated to be less than 5 per cent of the left lung structure. A huge cavity, measuring 9 by 5 cm., traversed the septum to involve both upper and lower lobes, and there were numerous small abscesses and considerable bronchiectasis present. The lung was universally adherent to the parietal and mediastinal pleura, diaphragm and pericardium.

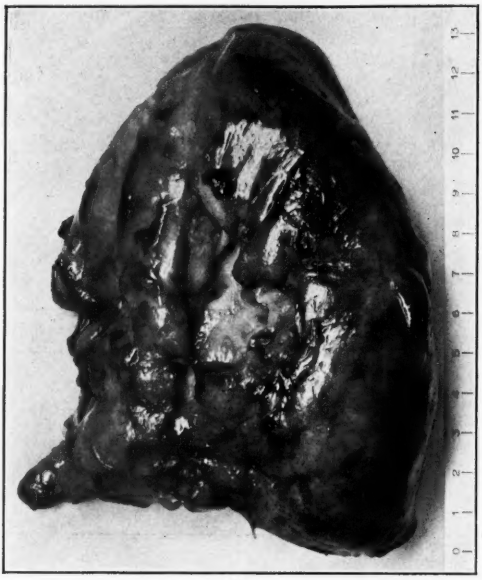
Operative Technic.—After injection of the second to tenth intercostal nerves, a long curved incision was made from the transverse process posteriorly to the internal

A.



B.

Fig. 2.—Ten days after external drainage, bronchogram revealing upper and lower lobe bronchi communicating with huge cavity.



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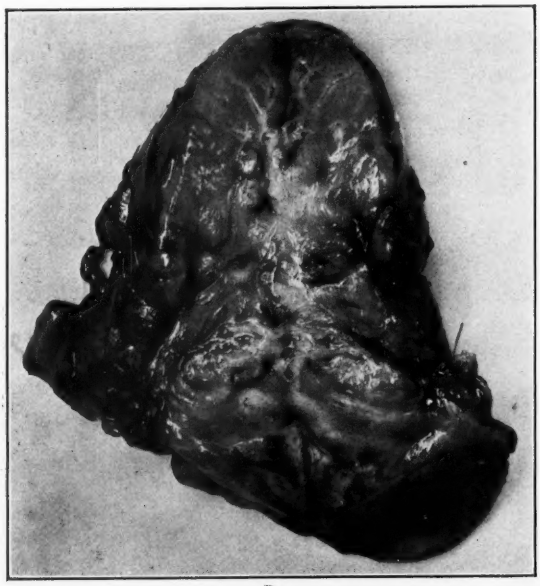


B.

Fig. 3.—*A*, External surface of lung after removal, showing drainage opening and underlying cavity. *B*, Cut surface demonstrating carnification, bronchiectasis and multiple small cavities.

mammary artery anteriorly following the course of the fifth interspace. The muscles were divided between clamps and the severed vessels were sutured. The fifth interspace was opened throughout its entire length without division of any ribs or cartilages. Adhesions were separated sufficiently to admit self-retaining retractor and ribs were spread. When sufficient dissection had been accomplished to allow wide spreading of the ribs, without tearing the adherent lung, this was done and excellent exposure obtained. The dissection was continued until the upper lobe was freed from the chest wall, mediastinal pleura, and pericardium with additional injections of novocaine between the adherent layers of pleura, near the apex, and into the phrenic nerve, when it was exposed, to paralyze the diaphragm and render

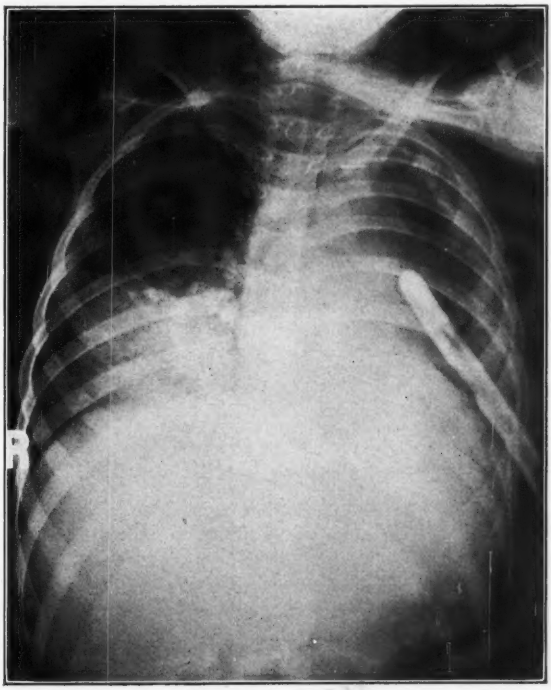


Fig. 4.—Four days after pneumonectomy, showing pneumonic consolidation right lower lobe. The partial horizontal line suggests middle lobe, but this was disproved by lateral projection.

it insensitive. The lower lobe was then freed from the chest wall and the diaphragm, except at the seventh interspace, where previous drainage had been instituted. An effort to clamp this area off and to separate it from the chest wall by the cautery to avoid contamination was unsuccessful because the pressure of the clamp severed their union, producing soiling.

When the lung was entirely freed from adhesions, the pulmonary ligament and hilus were injected with novocaine, the ligament separated, and the hilus grasped with a Roberts-Nelson tourniquet, using a double strand of heavy braided silk in place of the usual cord. The lung was then amputated, leaving a fairly long pedicle. Two additional single strands of heavy braided silk were tied tightly about the hilus and the tourniquet relaxed. No bleeding occurred. The handle was then unwound

sufficiently to cut it away from the silk loop, which was then tied down as an additional ligature about the hilus. Hemostasis was checked. A No. 32 catheter, with multiple perforations, was introduced through the old drainage opening at the seventh interspace and the wound was closed. This was accomplished by pericostal sutures of heavy silk approximating the fifth and sixth ribs and by continuous No. 1 chromic catgut to close the muscles in layers. The skin was closed with interrupted and continuous alloy steel wire. A greased rubber sponge was applied tightly about drainage tube to occlude the large opening and the patient returned to her ward with a pulse of 144, respirations 40, and blood pressure 80/40/40. During operation, a continuous intravenous drip of saline, totaling 350 c.c., and a blood transfusion of 250 c.c. were administered. Shortly after operation, an additional 250 c.c. of 10 per cent glucose were given intravenously and she was placed in an oxygen tent for twelve hours. Continuous suction was applied to her drainage tube.

Progress.—The postoperative condition was excellent for forty-eight hours. At this time, she developed pneumonia of the right lower lobe (Fig. 4). This proved to be type III pneumococcus pneumonia, from which she recovered by lysis, the temperature reaching normal on the eighth postoperative day. Her subsequent course has been uneventful, except for slight residual empyema, which eventually closed, and the necessity for removal of two pericostal silk sutures, which were the cause of small chronic sinuses. At present, three months postoperatively, the child is playing normally with other children and skates without dyspnea or other respiratory embarrassment. She weighs five pounds more than on admission. There is no bronchial fistula; her color is good, and her last hemogram as follows:

Hemoglobin—11 gm.
Red blood cells—4,440,000
Leucocytes—11,210
Polymorphonuclear neutrophiles—64%, of which 34 were nonfilament forms
Lymphocytes—28%
Monocytes—6%
Eosinophiles—2%
Basophiles—0%

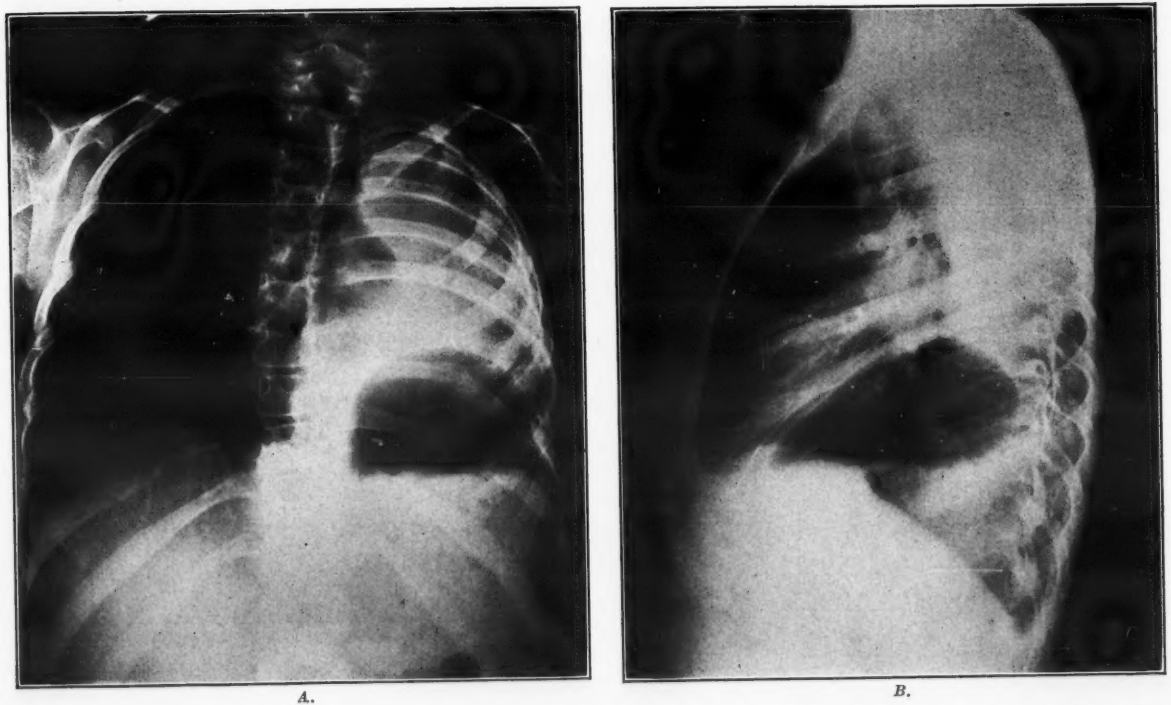
The vital capacity is 550 c.c. Her pulse rate is normally between 80 and 100 with ordinary daily activity. A recent electrocardiogram shows no change from the previous examination.

Her last x-ray (Fig. 5) reveals displacement of the heart and mediastinum to the left, elevation of the left diaphragm, and compensatory hypertrophy of the remaining lung.

Figure 6 depicts the intercostal incision and, below it, the drainage opening at the seventh interspace.

TECHNIC OF LOCAL ANESTHESIA

The technic of the anesthesia has been developed from extension of the field block technic for rib resection in the treatment of empyema and partial thoracoplasty. It has been used in three lobectomies, three thoracic explorations, and on this pneumonectomy. In its present state, it consists of the use of 0.5 per cent novocaine in saline solution to produce a series of wheals over the intercostal spaces, second to the tenth or eleventh, at the edge of the erector spina muscle (Fig. 7). After the first, these are made painlessly from beneath the skin. Through these wheals, the appropriate nerves are injected with about 5 c.c. of 1 per cent novocaine to each. If the incision is to be carried



A. *B.*

Fig. 5.—Three months after pneumonectomy, there is marked displacement of mediastinum and elevation of left diaphragm with considerable pleural thickening. No definite pneumothorax present.

to the midline anteriorly, the crossed innervation from the opposite side has to be interrupted by a band of novocaine at this point. Towel clips, used in the upper pectoral region, require additional local in-

Fig. 6*A*.

Fig. 6*B*.

Fig. 6.—The patient three months after pneumonectomy. Anteriorly may be seen the healing sinuses from which infected sutures were recently removed. Beneath scapula is small granulating area through which drainage was maintained.

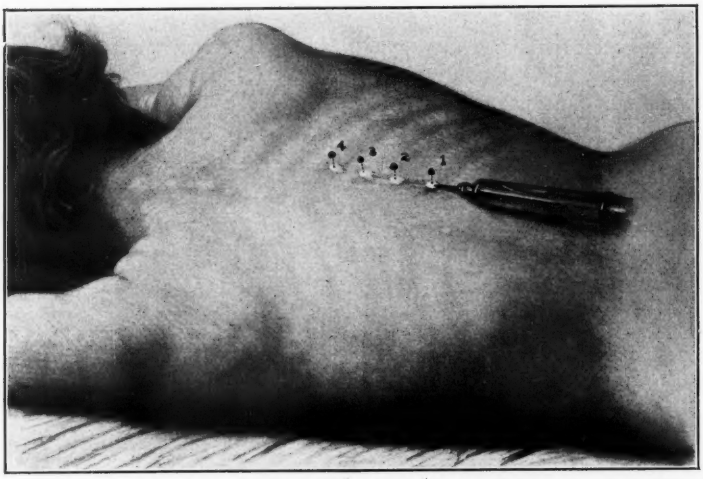
jection of each spot with novocaine because of the cervical plexus innervation inferior to the clavicle. Ten minutes after the last injection, the anesthesia is checked by the needle and finger method. If

not complete, those nerves which have not been interrupted are again injected. Anesthesia is usually completely effective for the chest wall and a large portion of the pleural surface. When the chest is opened, inhalations of carbon dioxide and oxygen under pressure may be necessary to prevent sudden complete collapse. This is unnecessary if pneumothorax has been previously instituted or if the lung is extensively adherent. The injection of the phrenic nerve in the thorax, when exposed, interrupts the diaphragmatic innervation both sensory and motor. The pulmonary ligament and the hilus of the lung are sensitive areas and have to be injected with 1 per cent novocaine,

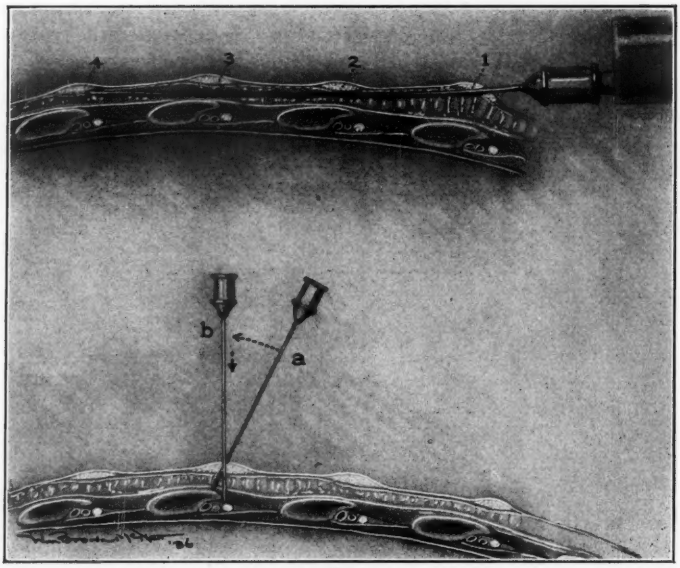
Fig. 6*C*.

avoiding injury to the vessels by superficial penetration. Handling of the free pleura, particularly on the mediastinal aspect and above the hilus, produces cough and some discomfort. Pouring 1 per cent novocaine over this area and maintaining its application with gauze sponge, saturated with the solution, while one is dissecting adhesions or exploring the remainder of the thorax, produces insensitivity here also. Occasionally, near the apex, additional infiltration has to be made between the layers of adherent pleura since this is above the field of intercostal block. As previously stated, children have been prepared by the preliminary injection of fairly large amounts of morphine in divided doses and adults by the use of ⅙ gr. morphine,

supplemented by rectal injection of tribromethanol (avertin), 40 to 60 mg. per kilogram, depending on the type of individual. Under these circumstances, the cough reflex is not abolished although it is definitely decreased.



A.



B.

Fig. 7.—*A*, Location of wheals made with 0.5 per cent novocaine by subdermal injection. *B*, Diagram of subdermal infiltration and of accurate method of release of intercostal nerves by "walking off" lower edge of nerve.

The disadvantages of this method are the same as those for most operations under local anesthesia, namely, the slightly longer time required, the multiplicity of areas to be injected, and, of course, the psychic shock unless analgesia is well gauged. Occasionally, in some of our earlier cases, handling of the hilus and mediastinal pleura produced such excessive cough as to require short ethylene or cyclopropane inhalation. This is more likely to occur in cases with a clean pleura.

The advantages lie in the great decrease in the amount of shock for the same procedure, or the more extensive procedure possible at one-stage as compared to inhalation types. The constant bombardment by the multiple stimuli of the nerve centers is not prevented under inhalation anesthesia although it is not appreciated by the intelligence of the patient, and, when added to blood loss, exposure of internal organs, etc., contributes greatly to the production of shock. When conduction is interrupted by novocaine injection, the stimuli do not reach the nerve centers. Second, one avoids the difficulty of certain complicated types of anesthesia administration, such as intratracheal, and the necessity for additional special knowledge for its arrangement, and, if necessary, even the need for an especially capable anesthetist; third, the ability to work accurately and without haste; fourth, the maintenance of the cough reflex for expulsion of pus or blood as the lung is manipulated; and fifth, the considerable improvement in immediate postoperative convalescence. It bids fair to be a definite factor toward decreasing the mortality of such extensive procedures as lobectomy and pneumonectomy often prove to be.

SUMMARY

1. A brief résumé is listed of the 41 reported cases of pneumonectomy resulting in a mortality of 39 per cent, reduced in the last 30 cases to 30 per cent.

2. An additional case of successful one-stage pneumonectomy for suppuration is reported, which, so far as we know, is the first to be done under local or field block anesthesia.

3. The technic of the anesthesia is outlined. Its advantages and disadvantages are stated.

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Department of Reviews and Abstracts

CONDUCTED BY DUFF S. ALLEN, M.D., ASSOCIATE EDITOR

Selected Abstracts

Pulmonary Cystic Disease. William C. Pollock. Am. Rev. Tuberc. **34**: 527, 1936.

Bronchoscopic and bronchographic observations have shown definite evidence of pulmonary cystic disease in the three patients whose case histories are given. Ten years' observation of one of the patients with no "significant" change in the pulmonary condition is the only outstanding feature in the review of the case histories.

Localized pulmonary emphysema may resemble pulmonary cystic disease, and it is likely that confusion of these conditions may occur. The differentiation between pulmonary cystic disease and spontaneous localized pneumothorax is important.

In both conditions a rarefied area is seen on the x-ray film; both conditions may present fine, dense lines in the rarefied area. The lines in spontaneous pneumothorax are straight and extend from visceral to parietal pleural attachments. These lines usually widen and are wedge-shaped at the base. The fine lines seen in an x-ray film of pulmonary cystic disease represent cyst walls and are not taut. The lines run downward, outward and upward and usually arise from the region of the mediastinum. Long sweeping curves with no widening at the base are seen.

Thoracentesis with injection of lipiodol may demonstrate cyst walls too delicate to be seen in an ordinary x-ray film. Apparent large cysts may be collections of small cysts with very thin walls.

The interesting observation is made that in patients with pulmonary cystic disease contralateral pulmonary hypertrophy is not evident in contradistinction to other conditions in which the function of one lung is disturbed. This may be for the reason that in cystic disease the air enters the cystic areas; therefore less pressure is exerted on the other lung.

The gradual onset of symptoms in pulmonary cystic disease, occurring usually in middle life, is contrasted with the typical history of sudden onset in spontaneous pneumothorax. Progressive dyspnea

finally ending in varying degrees of physical disability may indicate that the etiologic factor of a congenital character was present with actual cyst formation in the lung occurring later in life.

Brian Blades.

Acute Putrid Abscess of the Lung. Harold Neuhof and Arthur S. W. Touroff. Surg. Gynec. Obst. **63**: 353, 1936.

Divergent ideas on the management of putrid abscess of the lung, regarding both methods of treatment and the time treatment should be instituted, are the result of conflicting conceptions of etiology, pathology and pathogenesis.

The treatment advocated is largely based on the following conception of pathology of putrid pulmonary abscess. Pulmonary abscess, the result of known or assumed aspiration, begins in and distal to a small bronchus. The inflammatory and later necrotizing process is, therefore, only a short distance from the pleura. Early pleuritis is considered a constant accompaniment creating fibrous adhesions between overlying parietal and visceral pleura. Cavitation is thought to occur within seven to ten days of the onset of infection. The position of the lesion is "always" superficial, although the location may be such that adhesions form between adjoining lobes or between lower lobe and diaphragm. The authors believe that abscesses so situated have been erroneously called "central or hilar abscesses."

An acute pulmonary abscess is considered as a solitary, spherical, unilocular lesion associated with "walling off" pleural adhesions. The shell of lung tissue between the abscess and the visceral pleura is described as essentially avascular and varying from one-fourth inch to less in thickness.

Fibrosis of the wall of the abscess cavity and surrounding pulmonary parenchyma occurs in the "subacute stage." Spillover infections may result in multiple cavity formation. Bronchiectatic changes occur. The danger of acute gangrenous bronchopneumonia at this stage is emphasized. An insidious transition from subacute to a chronic stage may follow. Spontaneous subsidence is unlikely once the abscess is chronic.

An arbitrary line is drawn by defining "a putrid abscess acute, when it is of less than six weeks' duration from the time of onset of the first symptoms referable to it."

The method of treatment advocated applies to "hospital cases," that is, cases of acute lung abscess that are referred to the hospital because of unsatisfactory progress. The existence of a mild type of pulmonary abscess which may subside spontaneously is recognized.

Indications for operation are divided into imperative or elective. Comparison is made to the management of acute appendicitis. Ful-

minating cases require immediate operation; elective operations are performed on those patients showing no evidence of spontaneous recovery. Clinical manifestations determine the question of operative intervention in individual cases.

The high incidence of morbidity and mortality following any treatment of chronic pulmonary abscess and the low incidence of cure following conservative treatment of acute pulmonary abscess constitute an argument for early operation.

The success of the one-stage operation for acute pulmonary abscess depends on precise localization. The incision must be placed where lung and overlying pleura are adherent. Roentgenographic and bronchoscopic examination are of prime importance. Location of pain may be helpful. Physical signs are often misleading. Fluoroscopy and the use of radiopaque markers fixed to the skin may determine the line of incision.

A detailed description of the one-stage operation is given. The authors have employed the two-stage operation occasionally when the lesion faced an interlobar fissure or diaphragm. In all the other cases reviewed, a one-stage procedure was performed. The use of any type of cautery is not recommended. Correct surgical approach over the avascular shell of lung tissue makes sharp cutting instruments preferable.

Thirty-seven cases are analyzed. Ten of these had perforated; two were atypical, being derived from the mediastinum. All the remaining twenty-five patients are considered cured; although eleven have not been observed long enough for final classification. The excellent results convince the authors that management of acute pulmonary abscess should not differ from that of other accessible abscesses.

Brian Blades.

Bilateral Lobectomy for Bronchiectasis. Ivor Lewis. Brit. J. Surg. **94**: 362, 1936.

A case of successful bilateral lobectomy for bronchiectasis is presented. The following special considerations are mentioned.

Radiography: Obviously the extent of the disease must be determined by introducing lipiodol into the entire bronchial tree.

Vital Capacity: The considerations applicable to pneumonectomies or unilateral lobectomies differ in unilateral cases because after the first operation a partially diseased lung must be relied upon. After the second operation the respiration must be maintained by the recovered lobe or lobes on the side first operated on. The author believes that the adequacy of the vital capacity can be determined by the patient's reaction to preliminary pneumothorax.

Anesthesia: The author prefers spinal anesthesia. He suspects that an endotracheal catheter by its trauma may cause tracheobronchitis and is particularly contraindicated in bilateral cases. Positive pressure anesthesia is rejected because "positive pressure anesthesia must tend to distribute pus and any particulate matter throughout the lungs." The same danger is anticipated when the remaining lobe is inflated as the chest is being closed at the completion of an intrathoracic operation. The author believes that the safer way to secure early reexpansion of the lung is to aspirate the pleural cavity with a pneumothorax apparatus before the patient leaves the operating room.

The stages of bronchiectasis are divided into dry, septic, and putrid. The dry stage is considered too early for surgical intervention; the putrid too late. The opinion is expressed that operative removal should be performed in the second or septic group. There are a considerable number of cases suitable for bilateral lobectomy.

Attention to the following details in technic and management is urged: (1) preoperative postural drainage, "good food"; (2) one-stage operations; (3) preliminary pneumothorax; (4) multiple mattress suture of pedicle; (5) "water seal" closed drainage of pleural cavity; (6) lightweight dressings, preventing interference with respiration; (7) alternating position of patient to prevent hypostatic pneumonia.

Brian Blades.

A Study of the Lower Lobe of the Lung. Joseph Levitin and Harold Brunn. Arch. Int. Med. **57:** 649, 1936.

The authors believe that the lower lobes of the right and left lung are divided into two distinct parts, namely, a superior division and an inferior division. Evidence is presented that embryologically each portion develops from a separate anlage. A fissure separating the two parts may be seen in the developed lung. They believe that each portion of the lobe has its own bronchial distribution.

The clinical importance is emphasized. The pleural reflection in the fissure may be seen in roentgenograms and is often misinterpreted as a pleural adhesion. The authors state that the definite anatomic structure accounts for numerous disease processes, the localization of which has not previously been understood. Position of the diaphragm in the x-ray film is important, as the lesion may appear high in the chest or low behind the diaphragm. When the process is high in the roentgenogram, it may be erroneously called central pneumonia; when it is low, the portion may be mistaken for encapsulated fluid.

Roentgenograms are presented illustrating involvement of superior and inferior division of the lower lobes.

Brian Blades.

Book Reviews

DISEASES OF THE AIR AND FOOD PASSAGES OF FOREIGN BODY ORIGIN. By Chevalier Jackson, M.D., Sc.D., F.A.C.S., LL.D., Professor of Bronchoscopy and Esophagoscopy, Temple University, and Chevalier L. Jackson, A.B., M.D., M.Sc. (Med.), F.A.C.S., Professor of Clinical Bronchoscopy and Esophagoscopy, Temple University. 994 pages with 2,000 illustrations including 3 plates in colors. Philadelphia and London, 1936, W. B. Saunders Co.

This volume represents an important contribution to the literature of diseases of the air and food passages of foreign body origin. The first part is devoted largely to the clinical aspects of the foreign body problem and is of value to the general practitioner, the internist and the pediatrician, as well as the endoscopist.

In the chapter on etiology of foreign body accidents the various factors are discussed and many illustrative cases are cited. The chapter on pathology is supplemented by three plates in color. The various classes of foreign bodies, the changes produced in the foreign bodies, and the reaction of the tissues are discussed. The mechanism of bronchial obstruction and its influence on bronchial drainage, drowned lung, and pulmonary abscess constitutes an important part of this chapter.

Considerable space has been allotted to a consideration of the symptoms and the diagnosis of foreign bodies in the air passages. This is of particular interest to the practitioner, who commonly is the first to see these cases. The mechanism of the physical signs viewed from an endoscopic standpoint aids greatly in their proper interpretation. The technical problems for the introduction of endoscopic tubes are briefly stated. Mechanical problems deal with the general principles involved in the employment of the various forceps used in foreign body removal and should be supplemented with the data listed in the tabulated section. The method of handling cases of foreign bodies in the gastrointestinal tract undoubtedly represents the best plan of treatment and should be of particular interest to gastroenterologists and surgeons.

The second part, which constitutes a considerable portion of the volume, has been devoted to a tabulated experience in the peroral removal of foreign bodies from the air and the food passages. It contains data secured from an experience of over 2,500 cases of foreign bodies. This was arranged with the object of being of maximum use to those consulting the literature in reference to the removal of foreign bodies. The illustrations of the foreign objects are shown, actual size. The age of the patient, the size of the endoscopic tube and the instru-

ments employed, the particular difficulties encountered, the mechanical problem met with and its solution are all shown in tabular form. The duration of the operation is given as an index to the difficulties encountered, and the efficiency or inefficiency of the method used in that particular mechanical problem. By comparative study of the data secured in the actual case of foreign body with those of a parallel case contained in these tables, the method of removal is no longer a matter of chance; instead, it has a scientific basis and is a problem for those properly qualified and equipped.

Louis H. Clerf.

El Tratamiento Medico-Quirurgico de las Supuraciones Pulmonares. By Hernan Oyanguren M. 91 pages, Leblanc, Santiago, Chile, 1936.

This short monograph is a study based on fifty-four cases of pulmonary suppuration from the Hospital San Jose and the Hospital San Francisco de Borja of Santiago, Chile. The author draws a distinction between pyogenic and putrid suppurations of the lung. He concludes that the pyogenic suppurations have a favorable prognosis and that they recover spontaneously in 75 per cent of the cases. On the other hand, putrid suppurations have a bad prognosis regardless of whether they are at first of the pyogenic variety later becoming putrid, or putrid from the beginning. In his opinion pyogenic suppurations present usually rather well-defined cavities with fluid levels, but putrid suppurations less often show distinct cavities. Remissions and relapses are frequent, especially in the chronic and putrid forms. Pneumothorax is recommended for acute or subacute central pyogenic cases which are well drained through the bronchial tree, but the author is not enthusiastic about pneumothorax in the putrid cases or for the peripheral infections of either type. He condemns phrenic exeresis in all cases of pulmonary suppuration. He considers that direct surgical methods are applicable in young patients in subacute and in some acute cases. He considers them not applicable to patients beyond sixty years of age and in the very chronic and diffuse forms. Pneumotomy is often insufficient. Not only must one drain the lesion but the involved tissues must be destroyed and the necrotic sequestrum which has kept up the suppuration must be removed. The author evidently favors beginning the treatment of a case with nonsurgical methods and the utilization of surgery only after a trial period of about two months has indicated that spontaneous recovery will not occur. During the period of waiting he is inclined to use arsenicals and antigangrenous serotherapy in the putrid suppurations and antiseptics with vaccine therapy in the pyogenic suppurations. He also recommends the use of anti-amebic treatment in certain cases.

Evarts A. Graham.

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Twentieth Annual Meeting of the American Association for Thoracic Surgery

Dr. Hans Jacobaeus of Stockholm, Sweden, will be the guest of the Association at the meeting in Saranac Lake on May 31, June 1 and 2. He will discuss "bronchospirometry" and its use in determining the indication for thoracoplasty in cases of bilateral tuberculosis.

The headquarters of the Association for the meeting will be the Hotel Saranac. Dr. Edward S. Welles is chairman of the local committee on arrangements.

The published program will be mailed to members about May 1. Nonmembers desiring copies before the meeting may secure them by writing to the Secretary.